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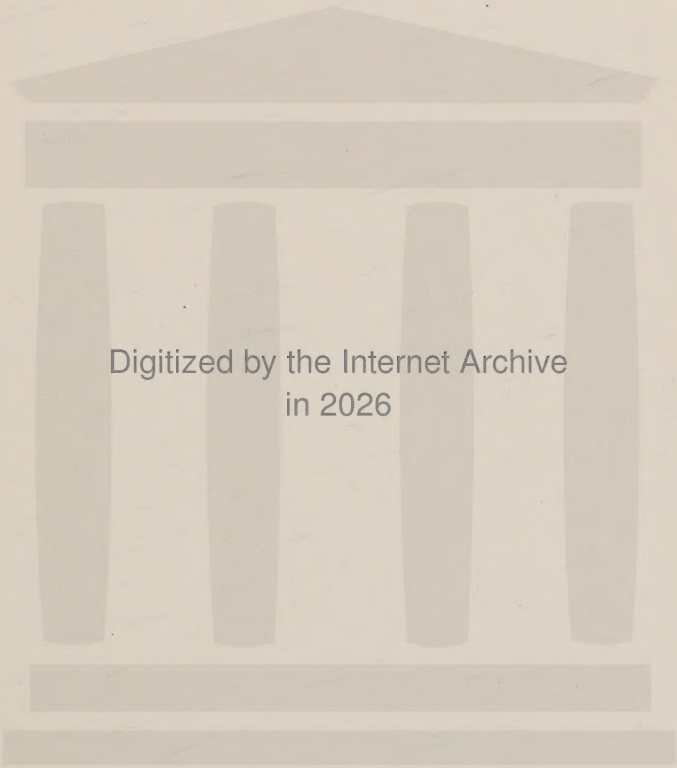
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USE OF WATER
IN
IRRIGATION

BY

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THIRD EDITION

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TO

THE MEMORY OF

My Mother

50,081

PREFACE TO THIRD EDITION

During the decade that has elapsed since the first edition of this work was published the practice of irrigation has been much improved, the farmers' part in irrigation development better understood and appreciated and the fundamental principles of irrigation farming more fully elucidated.

To record these changes aright and to present in summarized form the knowledge that has been gained on different branches of the subject since 1915 it has been necessary to add a number of new articles and to rewrite and enlarge much of what appeared in the earlier editions.

The author hopes that this latest effort on his part and of those who have been associated with him will bear fruit and that this revised and enlarged edition will continue to be a safe guide to irrigation practice in this country.

S. F.

Berkeley, California.
December, 1925.

PREFACE TO THE SECOND EDITION

In this edition the typographical and other minor errors of the first edition have been corrected, the article on the measurement of water revised and enlarged and a new article added on sewage irrigation. The most important change consists in the addition of a new chapter on the Use of Water in Foreign Countries.

The author takes this opportunity to express his appreciation of the widespread interest taken in the work, particularly by college professors and instructors who have introduced it as a textbook, and he trusts that the information added pertaining to irrigation in other countries may render the book still more serviceable for instructional purposes.

S. F.

Washington, D. C.
June 19, 1916.

PREFACE TO FIRST EDITION

It is well to recognize at the outset that irrigation is a many-sided subject. The heavy drafts which it makes on scanty water supplies and the close relationship which it bears to other uses of water call for wise legislation and efficient control on the part of state governments in the granting and protection of water rights and the equitable distribution of water supplies. These comprise the legal and administrative features of irrigation. Again, enormous quantities of water have to be stored annually in the mountains, pumped from wells, diverted from torrential streams, conveyed around hills and across valleys and finally delivered to farmers. The accomplishment of so great a task calls for high ability and broad experience on the part of engineers in designing and constructing the needed works, and these constitute the engineering side of irrigation. Then there is the agricultural side of irrigation which transcends all others in importance, in that it deals with the production of profitable crops. All other phases of irrigation are but means to an end. The one great purpose is to transform desert places into gardens and orchards where the highest type of American citizens may establish homes. Lastly, running all through the subject like threads in a fabric, are to be found such features as proper organization, cooperation, good management and profitable returns. These may be grouped under the economic side of irrigation.

No work on American Irrigation would be complete that did not embrace all of these salient features. On the other hand, the time required to prepare so much material would cause the first part to be out of date before the last was written. So it has been deemed best to consider but one phase of the subject at a time and to publish the material which properly belongs to that phase in a separate volume.

The volume here presented deals with the agricultural side of irrigation under the somewhat broad title, Use of Water

in Irrigation. It aims to benefit at least three classes of readers: The first comprises the new settlers and those who are looking to the West as a suitable place to establish homes; the second includes the irrigation farmers and those who are interested in irrigated agriculture; and the third class comprises students in agricultural high schools and in the agricultural and engineering classes of colleges and universities. The subject matter is confined almost exclusively to the irrigated farm and to the problems which confront the irrigator. In this respect it is an Irrigator's Handbook. The legal, economic and engineering phases of the subject are touched upon but only in so far as they affect the welfare of the farmer. Considerable space has been given to methods of preparing land and applying water for the reason that the manner in which these are done determines to a large degree the profits derived by the farmers and the success of canal companies. Considering the rich soil and favorable climate of arid America, the average yields under irrigation are small. This is mainly due to the adoption and use of faulty methods in watering fields and maintaining moisture conditions in the soil. It is hoped that out of the many methods herein described the farmer may adopt those best suited to the conditions on his farm and thus pave the way for profitable returns.

The manner in which water is used in irrigation as described in these pages is nation wide. The same care and attention which were paid to the irrigation of cotton and sugar cane in the Southwest, to rice in the Gulf states and to truck and fruit crops along the Atlantic seaboard were given to the irrigation of forage and cereal crops in the Mountain states and to vineyards and orchards along the Pacific. To cover so wide a field is much beyond the range of experience of any one man and in this connection the author gratefully acknowledges the assistance rendered by members of the Division of Irrigation Investigations of the Office of Experiment Stations, U. S. Department of Agriculture. For more than a dozen years this faithful band of technically and scientifically trained men have worked with and for the irrigators in their efforts to increase the productivity of land, establish homes and create more prosperous farming communities through the agency of water wisely used.

Whatever of merit this publication may possess is due in the main to the writings and views of these coworkers in the development of irrigation in this country. It records the experiences gained in the field and laboratory rather than what may be compiled in a library.

The author likewise desires to acknowledge his indebtedness to the Honorable David F. Houston, Secretary of Agriculture, for permission to publish this Handbook and to Dr. A. C. True, Director of the Office of Experiment Stations, for permission to make use of the publications and illustrations of the Office.

S. F.

WASHINGTON, D. C.
December, 1914.

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USE OF WATER IN IRRIGATION

CHAPTER I

INTRODUCTION

In the earlier stages of the development of the West, the mining of valuable ores was the chief occupation of the inhabitants and the principal source of revenue of the new commonwealths. In more recent times, the value of the products derived from the soil, and more especially from irrigated soils, has far surpassed that of the product of the mines. In California for example, the value of the gold, silver and copper produced in 1924 was $22,079,000; the value of the soil products was $450,000,000. Irrigation farming has become the chief industry of the West not merely because of the food and clothing it supplies but also the support it lends to other industries. The vast area of native grasses could not be used to the best advantage in feeding livestock if it were not supplemented in times of drought and winter storms by forage grown under irrigation. The health and comfort of urban populations are maintained by what the farmer produces, and these products furnish raw material for the manufacturer and traffic for the transportation company. Besides, there is a profitable exchange of commodities between the farms and the mines and between country and city people. Of still greater importance is the stabilizing effect of rural communities upon the various activities and general welfare of the western states.

On account of the aridity of the climate, progress in agriculture has been largely the result of the artificial wetting of the soil. Water from melted snow on high ranges and tablelands has been conveyed long distances to newly made farms. Worthless desert growth has been removed so that profitable crops might be grown; and new homes, new towns, and new industries have

been established in what was formerly a forbidding desert. Over 20,000,000 acres of low-producing or barren lands have been reclaimed, and over 230,000 irrigated farms created. In such an achievement there is much that merits praise. There is also much that calls for criticism. Now that it is past, it is easy to discover where mistakes were made. The mistake of greatest magnitude, which entailed the largest loss of capital and the greatest privation and suffering on the part of settlers, arose from a false conception of the nature of the undertaking. It was generally believed that when a water supply was obtained for a tract of land, everything else might be safely left to settlers. This belief was based on the false assumption that irrigation farming did not differ from prairie farming under a humid climate. Promoters, financiers and engineers overlooked the fact that main canals and laterals formed but a part of an irrigation enterprise; that farm systems of irrigation had to be planned and built; that land had to be prepared for the ready and sufficient wetting of the soil; that the necessary equipment in buildings, implements and stock had to be provided; and that it required years of careful planning and hard work to put a farm on a paying basis.

In nearly all the irrigation development of the past 35 years, little attention has been paid to the farmers' part of the work, and in consequence progress has been retarded, settlers have been subjected to unnecessary hardships and suffering, and small returns have been received from the capital invested. Competent engineers have designed and built highly creditable structures to provide water supplies, but these engineering features, so essential as a means to an end, have overshadowed the more important although less attractive features connected with the farms. Planning an irrigation layout for a farm requires engineering experience and ability, coupled with a practical knowledge of irrigation farming. The making of such plans, the building of permanent farm ditches and structures, grading and smoothing the surface of fields, and the adoption of the most suitable means of applying water pertain to engineering rather than farming, and should be as carefully planned and supervised as the building of the canal which conveys the necessary water for the farmers' use.

This volume is intended to serve as a guide to the irrigator in carrying out that part of the work of irrigation which he is called upon to perform. It deals with those subjects in which he is specially interested, such as soils, climate, crops and water rights. Farm ditches and structures are described and illustrated, and considerable space is devoted to methods of preparing land and applying water. Those troublesome features of irrigation farming such as the delivery, measurement and duty of water as well as the treatment of alkali soils and the removal of waste water are also treated. A chapter is devoted to the standard crops grown under irrigation, in which the time and frequency of irrigation and the latest and best methods of growing such crops are discussed. The volume ends with brief descriptions of the use of water in foreign countries.

It is also intended to serve as a textbook for students who wish to become informed regarding irrigation farming so that they may the better aid professionally or otherwise those who follow that calling.

Extent of Irrigation in the United States.—The extent of irrigation in the United States is shown in the following table compiled from census data. The first column of figures gives the acreage actually irrigated in 1919 in each of the 17 western states and the Gulf states, the second column the acreage which the enterprises were capable of irrigating in 1920 and the third column the acreage included in enterprises either completed or under way July 1, 1920. In the last column of the table is given the estimated value of irrigated crops in each of the 17 western states and also in the rice belt of the Gulf states.

TABLE No. 1[1]

State	Acreage irrigated in 1919	Acreage enterprises were capable of irrigating in 1920	Acreage included in enterprises in 1920	Value of principal irrigated crops in 1919
Arizona	467,565	627,303	813,153	$ 34,190,780
Arkansas	143,946	179,013	246,480	*15,275,000
California	4,219,040	5,894,466	7,805,207	319,126,883
Colorado	3,348,385	3,855,348	5,220,588	100,215,136
Idaho	2,488,806	3,092,810	3,780,048	76,830,737
Kansas	47,312	67,853	102,562	842,161
Louisiana	454,882	728,742	851,211	*45,828,390
Montana	1,681,729	2,753,498	4,329,148	30,382,674
Nebraska	442,690	562,468	766,768	11,547,679
Nevada	561,447	704,708	1,382,036	12,380,593
New Mexico	538,377	696,119	961,879	11,400,144
North Dakota	12,072	34,235	57,476	267,148
Oklahoma	2,969	9,672	11,742	*53,442
Oregon	986,162	1,344,046	1,925,987	12,294,191
South Dakota	100,682	150,914	188,382	2,403,548
Texas	586,120	1,150,542	1,687,447	22,343,976
Utah	1,371,651	1,700,550	2,359,244	50,114,342
Washington	529,899	637,151	836,795	39,801,619
Wyoming	1,207,982	1,831,039	2,564,668	15,683,997
Totals	19,191,716	26,020,477	35,890,821	$800,982,440

* Estimated.

Agencies in Irrigation Development.—Out of a total of over 19,000,000 acres, the individual irrigator who has either built a ditch himself or formed a partnership with one or more neighbors has reclaimed and irrigated 6,848,807 acres. Next in order come the cooperative companies which are really larger groups of farmers acting together in building the necessary works. These two agencies have to their credit 70 per cent. of the reclaimed area. Public irrigation corporations, known as irrigation districts, and commercial enterprises were nearly equal in area of reclaimed land in 1920. The U. S. Bureau of Reclamation, companies operating under the Carey Act and the U. S. Indian Service, including a few small miscellaneous enterprises,

[1] Tables Nos. 1 to 5, inclusive, were prepared by P. A. EWING, Associate Irrigation Economist, Division Agricultural Engineering, U. S. Dept. Agr.

comprise the remainder of these agencies. The extent of land which was reclaimed by each at the close of 1919 is given in the following table:

TABLE No. 2

Agency	Acreage irrigated in 1919
Individual and partnership enterprises	6,848,807
Cooperative enterprises	6,581,400
Irrigation districts	1,822,887
Commercial enterprises	1,822,001
U. S. Reclamation Service	1,254,569
Carey Act enterprises	523,929
U. S. Indian Service	284,551
Miscellaneous enterprises	53,572
Totals	19,191,716

Cost of Irrigation in the United States.—The first cost of irrigation falls naturally into two divisions. One of these represents the cost of the works necessary to provide a water supply and to convey it within easy reach of each farm. The other represents the cost of preparing the land so that it can be irrigated, together with the cost of farm ditches and structures.

On account of topography, soil, value of water and other conditions the cost of preparing land varies widely. In Table No. 3 the minimum, average and maximum costs of such work for each western state are given.

TABLE No. 3

State	Minimum cost per acre of preparing land	Average cost per acre of preparing land	Maximum economic cost per acre of preparing land
Arizona	$ 7.50	$20.00	$40.00
Arkansas	5.00	12.50	30.00
California	10.00	25.00	50.00
Colorado	7.50	15.00	40.00
Idaho	7.50	15.00	40.00
Kansas	5.00	12.50	25.00
Louisiana	5.00	12.50	30.00
Montana	7.50	15.00	40.00
Nebraska	5.00	12.50	25.00
Nevada	7.50	15.00	30.00
New Mexico	5.00	20.00	50.00
North Dakota	5.00	12.50	25.00
Oklahoma	5.00	12.50	25.00
Oregon	7.50	20.00	50.00
South Dakota	5.00	12.50	25.00
Texas	5.00	20.00	50.00
Utah	7.50	17.50	30.00
Washington	7.50	20.00	50.00
Wyoming	7.50	15.00	25.00

The first column of figures in Table No. 4 represents for each state included the capital invested in irrigation works to July 1, 1920. The next column represents the estimated cost of preparing land based on the average cost per acre for each state as given in Table No. 3. The last column in Table No. 4 gives the total first cost found by adding the capital invested to the estimated cost of preparing land.

TABLE No. 4

State	Capital invested in irrigation enterprises to July 1, 1920	Estimated cost of preparing land irrigated in 1919[1]	Total estimated cost
Arizona	$33,498,094	$9,351,300	$42,849,394
Arkansas	7,183,322	1,799,325	8,982,647
California	194,886,388	105,476,000	300,362,388
Colorado	88,302,442	50,225,775	138,528,217
Idaho	91,501,009	37,332,090	128,833,099
Kansas	2,067,381	591,400	2,658,781
Louisiana	14,063,181	5,686,025	19,749,206
Montana	52,143,363	25,225,935	77,369,298
Nebraska	13,909,185	5,533,625	19,442,810
Nevada	14,754,280	8,421,705	23,175,985
New Mexico	18,210,412	10,767,540	28,977,952
North Dakota	1,857,118	150,900	2,008,018
Oklahoma	151,325	37,112	188,437
Oregon	28,929,151	19,723,240	48,652,391
South Dakota	5,465,248	1,258,525	6,723,773
Texas	35,072,739	11,722,400	46,795,139
Utah	32,037,351	24,003,893	56,041,244
Washington	29,299,011	10,597,980	39,896,991
Wyoming	34,326,328	18,119,730	52,446,058
Totals	$697,657,328	$346,024,500	$1,043,681,828

[1] Based on column 2 of Table No. 3.

In estimating the cost of preparing land for enterprises not completed in 1919 the same unit costs were used. These, when multiplied by the number of acres contained within completed and incompleted enterprises, are given in Table No. 5 and comprise a total expenditure by the farmers under irrigation enterprises, inclusive of the amount expended for like purposes prior to 1920 of $598,507,487.

TABLE No. 5

State	Estimated final cost of works	Estimated cost of preparing land in project[1]	Total estimated final cost of projects
Arizona	$34,615,064	$16,263,060	$50,878,124
Arkansas	7,283,522	3,081,000	10,364,522
California	225,799,123	195,130,175	420,929,298
Colorado	95,198,423	78,308,820	173,507,243
Idaho	97,019,717	56,700,700	153,720,417
Kansas	2,195,981	1,282,025	3,478,006
Louisiana	14,264,178	10,640,137	24,904,315
Montana	70,079,028	64,937,220	135,016,248
Nebraska	18,030,154	9,584,600	27,614,754
Nevada	22,648,747	20,730,540	43,379,287
New Mexico	20,440,646	19,237,580	39,678,226
North Dakota	2,072,766	718,450	2,791,216
Oklahoma	162,775	146,775	309,550
Oregon	41,585,742	26,880,920	68,466,662
South Dakota	5,500,748	1,886,415	7,387,163
Texas	39,860,871	23,010,840	62,871,711
Utah	33,835,641	29,759,625	63,595,266
Washington	37,684,591	12,743,020	50,427,611
Wyoming	51,500,288	27,465,585	78,965,873
Totals	$819,778,005	$598,507,487	$1,418,285,492

[1] Based on column 2 of Table No. 4.

The people of this country have been greatly interested in the construction of works to reclaim desert lands. Land agents and others engaged in the settlement of these lands have fostered this interest by magnifying the importance of such works and at the same time ignoring the heavy expense which has to be incurred by the settler before such lands can be made productive. The erroneous impressions, which have been formed in the minds of credulous people by land agents and press agents in giving out one-sided information by means of circulars, press notices and illustrated lectures, have been the indirect cause of great suffering and disappointment among the settlers of irrigation projects and of irreparable loss to capital invested in irrigation enterprises.

This volume will have served a useful purpose if it corrects some of these erroneous impressions. It is thought no one can peruse its pages without being impressed with the large amount of money which must be expended between the time water is ready to be delivered and the time when the farm is on a paying basis. The information which it contains has been prepared with the object of assisting the irrigator in the design and execution of that part of the work which he must perform. The measure of his success will represent the measure of the success of the irrigation enterprise of which he forms a part since it is the labor of the irrigators skillfully directed which determines the value of such properties.

COST OF WATER

In pioneer days costs of irrigation water were not generally a large factor in the total annual outlay of western farmers. The first Federal census of irrigation, taken in 1890, reported an average first cost of water rights of only $8.15 per acre, although their average value in that year was shown as $26 per acre, while the average annual cost of water per acre was only $1.07. During the last three decades, however, these costs have mounted very rapidly, and in some cases they are now approaching, if they have not already passed, a safe economic limit for any but very high-priced agricultural crops. Instances are not unusual in which the annual cost of irrigation water per acre now exceeds an amount that would have been considered a justifiable capital investment for irrigation works 10 years ago. This situation was recently the justification for making an extended study of cost of irrigation water in California. The survey included nearly 200 public utility water companies, irrigation districts, and mutual water companies, and about 70 private pumping plants. An effort was made to consider all the factors entering into cost of irrigation water, which necessitated a careful review of the methods of levying and collecting irrigation rates and taxes under the principal irrigation systems of the state. To arrive at comparable conclusions it was necessary to obtain the best figures available on the net duty of water under the various systems embraced in the investigation, and account was also taken of the differences both in duty and in annual cost of water to irrigators with the principal crops irrigated in California.

The general summary of annual cost of irrigation water in California[1] as given in Table No. 6 shows a wide variation.

TABLE No. 6

Type of enterprise	Number of enterprises considered	Annual cost					
		Per acre			Per acre-foot		
		Minimum	Maximum	Average	Minimum	Maximum	Average
Public utilities	46	$0.56	$32.67	$ 6.10	$0.30	$25.14	$ 4.27
Irrigation districts	37	0.90	24.69	7.57	0.37	22.19	4.80
Mutual water companies	111	0.83	60.07	15.51	0.40	50.91	10.62
Private electric pumping plants[1]							
Sacramento Valley	22	3.01	45.63	19.04	2.81	55.31	7.65
Santa Clara Valley	24	5.34	33.08	16.24	4.04	56.34	23.73
San Joaquin Valley	14	6.96	48.08	22.26[2]	1.56	18.42	7.21

[1] All of these were tested for plant efficiency.

[2] Average of 11 enterprises. Those enterprises for which acreage costs were not available had low acre-foot costs.

[1] Extracted from report on "Cost of Water to Irrigators in California," by HARRY F. BLANEY, Associate Irrigation Engineer, Division Agricultural Engineering, U. S. Dept. Agr., and published as Bulletin No. 8 by State Department of Public Works, Sacramento, Calif.

CHAPTER II

THE IRRIGATED FARM

1. Farm Settlement.—The settlement of land in a humid region differs in many essential respects from that in an arid region. If this truth had been earlier recognized, it would have saved western people from much privation and suffering and investors in irrigation works from heavy financial losses. The *laissez-faire* policy with its minimum of responsibility and supervision under which the prairie states west of the Mississippi River were settled is not adapted to the settlement of the irrigated lands of the West. Fertile, humid lands are ready for the plow and their cultivation can be carried on by the individual with little capital. Arid lands, on the contrary, require large initial expenditures in providing water and preparing land, each canal system furnishing water as a rule to many thousands of acres, and in addition are frequently so lacking in organic matter as to require special treatment for several years before they become suitable for general farming. Up to a few years ago, the prevailing custom was to provide a water supply for each of these large tracts of land and make little provision for its settlement and profitable production. Too frequently the inadequate provision made was worse than useless. This occurred when real estate agents were commissioned to sell irrigable lands to settlers irrespective of their fitness. Their character and qualifications were not considered important and if they had sufficient money to make the first payment, it sufficed. In the large majority of cases no bar was placed against land speculation so that lands in their native state were sold to overcredulous buyers in too large holdings at many times their real value. Furthermore, little help was given to settlers in planning a proper irrigation layout for their farms and in preparing the surface in such a way that it could be readily and uniformly watered. Settlers with little money and experience were obliged to plan and build the farm units—the

most important and often the most difficult part of an irrigation system. The results in too many instances were partial failures, abandoned holdings, delay in settlement, low production, small returns and bankrupt enterprises. On account of the large investment made to provide a water supply, and the annual expenditures necessary to operate and maintain the systems and pay interest on the investment, sound economy called for the earliest possible occupancy of the irrigable lands by the right kind of families, the transformation of raw land into productive fields and the largest obtainable returns from each farm in the shortest possible time. Only by following such a course could the solvency of the enterprise be maintained. The immense loss of capital in irrigation undertakings and the bankruptcy of so large a number of enterprises are convincing proof that this course was not followed. Dr. Elwood Mead says, in speaking of Government irrigation projects:[1]

> The evidence is conclusive that we must in the future pay more attention to settlement problems and the qualifications of settlers if we are to escape complications and losses that will discredit, if not terminate, this policy. We cannot go on ignoring the things which determine ability to make payments, while expending from $5,000 to $12,000 on 80-acre farms to provide water.

The most common causes of failure on the part of settlers are (1) lack of capital, (2) high rates of interest on temporary loans, (3) mortgaging farm incomes to pay for short-term loans resulting in defaulting taxes with their high penalties, (4) owning too much unproductive land, and (5) raising unmarketable or unprofitable crops.

The costly experience of the past in following faulty methods in settling irrigation enterprises and the rapid progress made in recent years in developing better methods seem to warrant the adoption of some such plan as is herein outlined for irrigation enterprises of the future.

1. In all irrigation enterprises of medium or large size, plans for farm systems of irrigation should form a legitimate part of the plans of the main works. Topographic surveys made in conjunction with soil surveys form a necessary basis for the

[1] *New Reclamation Era*, October, 1924.

planning of farm irrigation layouts. In such surveys and their accompanying maps, the elevation and character of the surface are recorded and those portions which are too steep, rough, stony or otherwise unsuited for irrigation are segregated from the irrigable portions. Such surveys likewise provide the requisite data for the location of headgates, supply ditches and other permanent farm ditches, for suitable land preparation and for the adoption of a method of applying water which will be both economical and efficient. Experience has shown that it is not enough to provide plans for settlers but that in many cases at least a fourth of each holding should be ditched, plowed, graded and seeded or a crop growing by the time the farm is handed over to the settler. Such work can be done better and more economically on a large scale with the use of proper equipment; the ditches, land grading and structures will serve as models for the rest of the farm; less capital is required on the part of settlers; returns are assured the first year of occupancy; and such preparatory work hastens the time when the entire farm is on a productive basis.

2. A carefully made soil survey forms the basis of land classification and valuation. Character of soil and subsoil; drainage requirements, present and future; suitable crops; types of farming and size of farm are some of the features of irrigation farming which soil surveys disclose.

3. Where large initial investments are required to fit lands for profitable production, a careful selection of settlers for such lands is a necessity. It corresponds to securing competent workmen to operate a factory. Perhaps the chief requisite for a settler on an irrigation enterprise is a good character. It is not essential that he understand irrigation, but he should be honest, willing to work and desirous of meeting all his obligations to his family, his neighborhood and his country. Such a man is usually willing to learn and the instruction he receives is put to a good use. It is seldom possible for colonization agents to secure families having much money. Those who are fortunate in this respect rarely settle on new land with its attendant privations and lack of social intercourse, educational facilities, churches and means of communication. About the only feasible plan is to select the right kind of people in regard to their moral fiber,

industry and perseverance, and assist them by advice and credit to attain success. Such settlers should have some money, but part of their property may consist in stock, equipment, supplies or credit. In the plan of settlement most favorable to settlers, first payments on land and water are required. Another requirement is that suitable shelter be provided for families and their stock with enough means besides for the necessary equipment and subsistence until crops are harvested.

4. Settlers, particularly the inexperienced, need to be rightly advised. Even the experienced can profit much from the advice of specialists. Sound advice is especially needed during the first year or two of occupancy when the farm is in the making. It is difficult and costly to correct mistakes once made. The settler should have disinterested advice in the selection of his farm so that the expenditures required to equip a farm of a given size for a particular type of farming can be met by his bank account or credit and that the labor in the family can operate such a farm with the prospect of securing profitable returns. After the selection of a farm comes the grading and preparation of land and the digging of ditches. As has been stated the plans for this work should be furnished the settler, but if he is called upon to carry them out, it should be done under technical advice. Technical advice should be had also in the planning and erection of dwellings and out-buildings so as to fit the building to the needs and means of the owner. More suitable buildings may be had under wise planning and the cost may be much reduced by purchasing selected material at wholesale rates and in carload quantities. The advice of the experienced agriculturalist is likewise urgently needed in adapting crops to soils, climate and markets, in the production of profitable crops, in establishing scientific systems of crop rotation, in farm management and marketing and, in short, in regard to the many essential features which long experience has shown to be sound and profitable to adopt in irrigation farming.

5. The giving of financial assistance to new settlers may likewise prove a wise policy. To begin with, the large majority require long-term payments for land and water. Converting desert land into productive farms is expensive and time consuming, and the returns from soil products during this period are

small. In view of these drawbacks, which are common to all reclaimed land, the payments on the principal should be small at first and gradually increase to the seventh or tenth year, when they can be equalized for the remainder of the years of payment.

Then money should be loaned to settlers under proper procedure and safeguards. The manner in which banks loan money to farmers often results, in the long run, in the bankruptcy of the borrowers. It is possible to make borrowing too easy. Too frequently money borrowed at a high rate of interest is expended for non-revenue-producing objects. Even when expended for reproductive improvements, it is not always done in the best way.

Loans to settlers should be closely supervised. The nature of the improvements which it is proposed to make with the borrowed money should be scrutinized to determine their income-yielding capacity. Determinations should also be made as to the adequacy of the security, the character of the borrower and his family and their ability to meet their obligations, barring unforeseen and serious setbacks. Finally, the loan money should be expended for specific purposes on a prearranged schedule and effectively supervised not only through the building or purchasing stage but also throughout the life of the loan.

Loans of the kind recommended can be safely made and in about nine cases out of every ten, the men and women who settle on unimproved, irrigable land need loans to secure the necessary stock and equipment so that they can carry on. The way in which one loan helped is told by George C. Kreutzer, late superintendent of the Durham State Land Colony at Durham, Calif.[1]

A young couple settled at Durham and had $3,000 capital. They purchased 41 acres, of which 36 acres were in alfalfa. The cost of the grading, ditches and alfalfa was $1,640, on which they paid down $656. A comfortable cottage cost $1,500, upon which was loaned $900. The settler built his own barn at a cost of $600, and purchased a team, wagon, cow and heifer, harrow, plow, rake, mower and other tools costing $850. Initial deposit on land was $461.50. He had to have a well and hand pump and $140 worth of lumber for chicken house and other outbuildings. His expenditures to this time were more than his

[1] See *Eng. News-Record*, Nov. 22, 1923.

original capital and he would have been in debt had he not sold his first cutting of alfalfa. Soon a half yearly payment would be due the board. Before the second cutting of alfalfa was harvested an inspection of the property was made. The alfalfa was past the stage of making good cow hay. The family was called upon and the young wife said that her husband was driving a tractor in a neighboring county, while the alfalfa had been let to a neighbor on shares. The neighbor was busy cutting his own field, and counted on spare time to farm the neighbor's field, where he got only half the crop. After several questions were asked, the young wife admitted that they were "broke" and a tear coursed down her cheek as she related that they had never been entirely without funds before. Of course they hadn't! They wouldn't have had $3,000 in the bank when he was 35 and she 29 if they had not been saving and careful. A conference was arranged and the husband sent for. At the conference a program was agreed to which provided for the purchase of sufficient dairy cattle to utilize the feed. The cattle purchased could be added to their assets and give ample security. The following week they had 11 high-grade cows instead of 2, and they were on the payroll. Their first week's check from the Dairymen's Association amounted to $48.47. They had borrowed $1,110 to make the purchase of cattle, payable in 36 monthly payments of $33.30 each. One week's check would meet it and leave $15 to buy groceries. His loans at that time amounted to $2,994.

That livestock note was paid on time and the farmer and his wife have progressed; their net worth increased from $3,000 in 1918 to $8,149 at the end of 1922. A loan at the right time rescued a somewhat hopeless situation and this family can now look forward to the future with confidence.

2. Location and Selection of a Farm.—Those who contemplate establishing homes in the rural communities of the West need have little concern over the healthfulness of the region. The elevation of the arable lands, the abundant sunshine, freedom from extremes in summer heat or winter cold, the bracing atmosphere with its low humidity and scanty rainfall, all tend to create an invigorating climate where malarial diseases are practically unknown save in a few localities and where other tropical and semitropical diseases have never gained a foothold. The character of the farmers is also an asset, since over 75 per cent are native born and the remaining per cent of foreign birth have come almost wholly from northern Europe.

While the prevailing characteristics of the climate of the West are its small amount of rainfall of a few inches to less than 20 inches in the cultivated valleys; its low humidity, varying from 20 to 65 per cent outside of the Pacific Coast area; and its sunshine during 60 to 75 per cent of the time, there is a wide diversity in winter temperatures, the length of the growing season, and the crops that can be successfully grown. In the warmer portions, winter temperatures may not go below the freezing point, the growing season is practically continuous the year through, and a large variety of crops can be grown ranging from hardy cereals to citrus trees and date palms. In the colder portions, on the other hand, winter temperatures may go as low as minus 30°F., the number of frost-free days may be less than 75, and the kind of crops that can be grown is accordingly limited to forage, cereals, roots, and small fruits.

The intending settler, in deciding where to locate, will be guided somewhat by the climate, land values, character of soil, crops that can be grown, transportation and marketing facilities, as well as the educational and social advantages. Those who prefer a mild winter climate and the choice of a wide range of production will be naturally attracted to the southern belt of the arid states which include Texas, Arizona, New Mexico, southern Nevada and the greater part of California. Those who prefer less oppressive summers on account of the heat, coupled with short winters and an occasional sleigh ride, will find a location suited to their tastes in the central belt of the arid region, extending from western Kansas through Colorado, Utah, Idaho, northern Nevada, and north on the Pacific Coast to Oregon and Washington. Those who desire cheaper lands with more plentiful water supplies and are robust enough to withstand cold spells in a land of abundant coal will do well to consider Montana, Wyoming and the Dakotas.

Having made a wise decision in regard to a location, the next task is to exercise equally good judgment in the selection of a farm. If the farm is to be irrigated, there are a number of features deserving careful consideration, that are of minor importance in farming under the natural rainfall. Some of these are the character of the surface and its native vegetation, the probable cost of preparing land for irrigation, the adequacy

of the water supply, the presence of alkali and the drainage requirements of the future. Some of these are discussed elsewhere and need only be mentioned here.

The native vegetation is the resultant product of all natural conditions affecting vegetation and may be taken as a fairly true index of the character of the soil, its behavior under cultivation and irrigation, and the farm crops that can be grown upon it. When tall sagebrush, cactus or little rabbitbrush is found on a tract, it is reasonably certain that the soil is fertile, easily worked, and well drained. A somewhat heavier type of soil, but highly fertile and productive, produces in its native state such plants as wheat grass, grama grass, buffalo grass and mesquite. The plants named are but a few that grow in combination with other plants on good soil. On the other hand, the presence of greasewood, creosote bush, saltwort, salt weeds and other similar plants is indicative of a heavy soil, more difficult to cultivate and containing more or less of the injurious salts grouped under the common name of alkali.

The cost of land preparation and farm systems of irrigation usually increases the first investment in land and water from 25 to over 100 per cent. It is, accordingly, to the interest of the prospective settler to purchase land, other conditions being similar, that can be cheaply prepared for irrigation. Land with steep slopes is not desirable for any crops unless it be for greater frost protection for orchards, since the application of water and all farm operations are rendered more difficult and costly. It is also difficult and costly to carry water over land that is cut up by ravines, has an uneven surface or irregular slopes. In other localities are to be found mesquite, dwarf oak, junipers, cedars and other natural growth that have to be removed before farm crops can be raised. As discussed elsewhere, it is more economical and insures a larger measure of success in the end for the colonization agents to prepare a part of each farm for irrigation and thus relieve the farmer for a time at least of a task in which he is not experienced and for which he may have no suitable equipment.

In the valleys and lowlands, or where good air drainage is lacking, frosts occur later in the spring and earlier in the fall than upon the adjacent ridges and tablelands, thus producing a shorter growing season for the same locality.

During the first stages of irrigation in the West, drainage was given little consideration. Continued irrigation, however, with its resultant waste of water, has caused some lands that were once dry to become wet and usually alkalized, necessitating drainage. On an average about 1 acre in every 7 that are irrigated becomes water-logged and the cost of reclaiming these wet lands ranges from $15 to $40 an acre, depending on the physical conditions of the locality. The inexperienced is not qualified to judge of the drainage requirements of the future regarding irrigated land and it is wise to secure expert advice in regard to such matters. The same procedure applies to many of the essential features of irrigation farming such as the character of the soil and subsoil, climatic conditions, kinds of crops to grow, type of farming to follow, necessary equipment and capital, gross production per acre, transportation facilities and markets.

At first social and educational advantages are rather limited in a newly developed section. Provisions for schools, however, are usually made a part of the administrative policy of irrigation projects and they are established whenever the attendance is sufficient to warrant such institutions. In the West instances are common where schools were organized as soon as some four or five children of school age resided within the district. Schools are closely followed by social and religious activities which tend to the uplift and betterment of the community.

At the beginning the farm has but a slight intrinsic value but as improvements are made and as social and educational conditions become better, its value rises. Again, as the community becomes better settled, small towns and villages may spring up which will tend to enhance its value still more. Even though proximity to a town and favorable social and educational facilities can not be had to the extent desired, the settler has it in his power to make his farm highly productive and valuable by the adoption of good methods of farming skillfully carried out.

3. Lands Open to Settlement.—Although the 17 western states include a land area of nearly one and one-fourth billion acres, only a relatively small part can be used for irrigation farming on account of the shortage of water. In the earlier stages of irrigation development, conditions were such that

individuals working independently or in small, unorganized partnerships could divert water from nearby streams and apply it to their farms. About 7,000,000 acres have been reclaimed in this way. Opportunities are still open to this class to secure surface-water supplies at moderate cost but they are to be found for the most part in localities somewhat remote from towns, rural communities and transportation. Opportunities for this class are also open to secure water by pumping in settled and developed communities. To cite the possibilities in this respect in one of the western states, it is estimated that 5,000,000 acres of Kansas is underlaid with water-bearing strata at depths near enough the surface to permit of water being pumped from wells at a lower cost per acre than that possible under the more recently constructed gravity systems.

On account of the remoteness of the source of water supply, the necessity for storage, the cost involved and other factors, it is seldom feasible in modern times to provide an independent water supply for each farm or small group of farms. About the only feasible plan is to build an irrigation system that will supply a large number of farms. Thus, to call attention to an extreme case, the Imperial Irrigation District of California has but one system, yet it supplies water to over 600,000 acres. The large expenditures necessary for such irrigation works have called into being a number of organizations which have for their object the financing, building and operation of irrigation enterprises. Thus, there are under the jurisdiction of the state, cooperative or mutual companies, irrigation districts and commercial companies. As agents of the Federal Government, there are the U. S. Bureau of Reclamation and the Indian Service. In all such enterprises, the building of works to provide a water supply must precede farming by irrigation. Indeed, it would be nearer the truth to state that there is a long-drawn-out transition period between the completion of works and the conversion of raw or dry farmed land into irrigated holdings. The rate at which land in irrigation enterprises has been so converted has been discussed by R. P. Teele[1] who based his conclusions on the returns to the Thirteenth and Fourteenth censuses. These are summarized in Fig. 1 and Table No. 7. In consequence of the years of time required to

[1] Teele, R. P., *Dept. Bull.* 1257, U. S. Dept. Agr.

settle land under irrigation systems, a large acreage in the aggregate of such land is unsettled. The acreage enterprises were capable of irrigating in excess of that irrigated in 1919 for each state and each type of enterprise is given in Table No. 7.

TABLE NO. 7

State	Excess over area irrigated in 1919, acres	Type of enterprise	Excess over area irrigated in 1919, acres
Arizona	159,738	Individual and partnership	2,406,949
Arkansas	35,067	Cooperative	1,821,898
California	1,675,426	Irrigation district	708,538
Colorado	506,963	Carey Act	280,369
Idaho	604,004	Commercial	977,562
Kansas	20,541	Bureau of Reclamation	426,074
Louisiana	273,860	U. S. Indian Service	199,935
Montana	1,071,769	State	1,759
Nebraska	119,778	City	4,312
Nevada	143,261	Other types	1,310
New Mexico	157,742	Not reported	55
North Dakota	22,163		
Oklahoma	6,703		
Oregon	357,884		
South Dakota	50,232		
Texas	564,422		
Utah	328,899		
Washington	107,252		
Wyoming	623,057		
Total	6,828,761		6,828,761

It is believed that the figures given in the preceding table are much in excess of the actual extent of land open to settlement in the respective states or under the various types of enterprises. This belief is based chiefly on the following facts: It is seldom that topographic and soil surveys are made of the lands included in the new irrigation enterprises. Hence, in selecting the lands to be included for such purposes, few accurate data are available to enable a close determination to be made of the percentage of such lands that is non-irrigable by reason of rough or uneven

surface or inferior soil. In the case of the formation of irrigation districts, more consideration may be given to the views of land owners involved than to the physical requirements of irrigation and cultivation. Again, areas of raw or dry-farmed land held in large holdings are most commonly included in enterprises of this kind, but as settlement advances, more and more of the total area is used for roads, corrals and building sites. Besides,

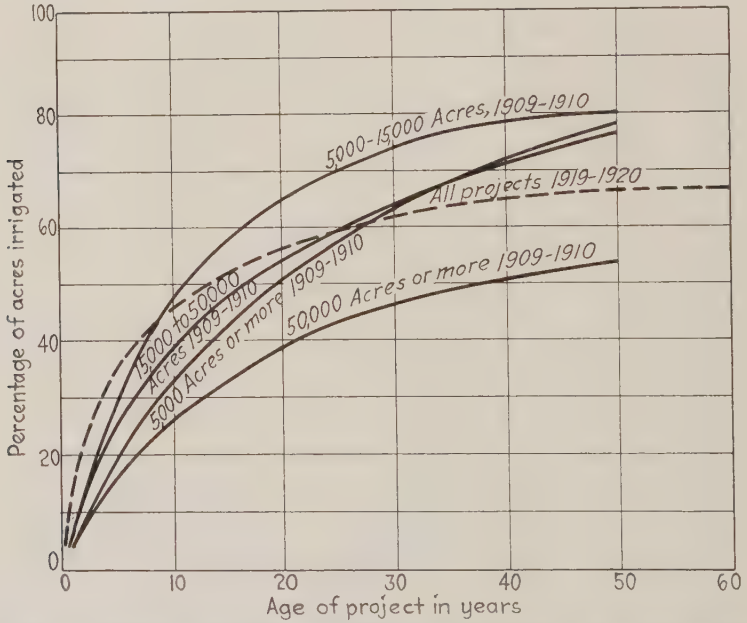


FIG. 1.—Rate at which land in irrigation enterprises in the United States has been put under cultivation. (Based on returns to Thirteenth and Fourteenth Censuses.)

for one reason or another, some land within the organization is not irrigated every year.

That the census figures in reference to the extent of land open to settlement require modification is further evidenced by the curve (Fig. 1) representing all projects 1919–1920. It will be noted that there is but a slight increase in the area irrigated between the thirtieth and fiftieth year of operation and practically no increase between the fiftieth and sixtieth years. This indicates that the irrigable land was almost wholly utilized, thus

leaving a balance of nearly 35 per cent which for reasons here given could not be irrigated.

The extent of land open to settlement in 1919 as given by the census is so large that even if a deduction of 35 per cent be made, there still remain 4,438,695 acres available for settlement.

4. Size of Farm.—The proper size of an irrigated farm depends on a number of varying conditions, some of which are briefly discussed below.

As regards climate, the dependable summer rainfall is of importance since the soil moisture derived from this source lessens to that extent the need for irrigation and the cost of providing and applying water. The duration of the frost-free period is likewise important since it controls to a large extent the crops that can be grown, and to a less extent the period of field work. In the colder and more elevated parts of the West, soil products are confined largely to forage crops and cereals, and for these fairly large farms are required in order to raise sufficient revenue to maintain a family, whereas in the warmer parts of the West a much larger variety of crops can be grown, many of which call for intensive farming and yield high returns per acre. As a rule, the more intensive the farming, the less is the acreage required.

Although it is necessary to adapt farm crops to the climate of the locality, yet in all but the coldest parts, the farmer has the privilege of a more or less wide range of selection, and upon his choice of crops will depend to some degree the proper size of his farm. As much labor may be expended on an acre of potatoes or sugar beets as on 2 acres of alfalfa or 4 acres of wheat.

The character of the soil and subsoil is a factor in determining the size of a farm. If the soil is fertile, deep, well drained and free from alkali, its productivity may be ten times as great as that of inferior land to be found, it may be, in the same locality. The inferior land may be fit only for pasturage or the growing of cereals, requiring the returns from a large area to support a family while 20 acres of the good land may keep a family in comfort.

The character of the farmer and his family and their work capacity constitute other factors. Some are physically able and experienced and may accomplish more in one day than the unfit or inexperienced can in treble the time. Some families receive

considerable aid from the work of their children. It is apparent, therefore, that, other things being equal, the greater the work capacity of a family, the larger should be the farm holding.

The size of the farm should be governed somewhat by the capital of the purchaser. A course that leads often to bankruptcy is to pay the first instalment on a large farm and have little left for equipment and development. Few new settlers have a just conception of the cost involved in putting an irrigated farm on a profitable basis. With those of small capital it is a gradual process, a few acres this year and a few the next. Meanwhile the interest on land and on water rights have to be met whether the land is idle or cropped. A safer and wiser course is to select a small farm and put it on a paying basis as soon as possible. Then if more land is desired, usually there are chances to acquire it from discouraged settlers at reasonable prices.

Such factors as diversification in crops, markets and transportation facilities all exert an influence on the area of land that should be cultivated. The diversified farm with good markets within easy reach need not be anything like as large as the stock farm far removed from markets.

Quite frequently the standard of living has as much to do with the size of the farm as anything else. Packard[1] says:

> The French peasant living in small rural villages, walks to his two or three acre strip of land early in the morning, with a hoe on his shoulder, a hunk of bread in his pocket and a flask of sour wine to quench his thirst. His wife keeps the house, cooks over the open fire, gathers the twigs into fagots from the neighboring forest, herds the cows and the goats along the road side, makes the clothes, takes the rabbits and the vegetables to the market place once a week, where she joins in the gossip of the women of the neighborhood. Contrast this with the American orchardist or dairyman with a 40-acre farm. He has an income sufficient to afford a good house, barn and outbuildings, modern plumbing, electric lights and an automobile. His table is filled with good things to eat and his sons and daughters may go to college. A man cannot lead the life of the 40-acre man just described on a peasant's income. Either the farm must be large enough or well-managed enough to support a good living or the owner must get along on less. Either the farmer must make a satisfactory income or he must cut down his expenses.

[1] PACKARD, WALTER, "How Large Should a Farm Be?" in *The Irrigation Review* for May, 1924.

Irrigated farms throughout the West may be grouped as follows:

1. The subsidiary small farm of 2 to 5 acres which serves as a home for the laborer, the mechanic, the clerk, or the prospective farmer and affords a means of eking out his pay checks by the growing of vegetables and fruits; keeping livestock such as poultry, bees, hogs and a cow; and furnishing healthy and profitable employment outside of school, office and workmen's regular day.

2. The small farm of 10 to 20 acres from which all the income of a family is derived. This comprises a wide range of crops and combinations of crops intensively farmed. Its characteristic feature is a high return per acre at the cost of a large amount of manual labor and a low investment in farm machinery.

3. The diversified farm of 30 to 60 acres. Statistics show that a large percentage of irrigated farms come within this range of acreage. This is particularly true of localities having a mild climate, a long growing season and good markets.

4. The diversified farm of 50 to 100 acres. Such farms are well adapted to families having boys to help with the field labor. They are also adapted to localities somewhat remote from transportation and urban population.

5. Combination farms consisting of 20 to 40 acres of irrigated land, 40 to 80 acres of dry farming land and 640 acres or more of grazing land. The agricultural lands of the West consist of large areas of non-arable grazing lands, smaller areas of arable lands and still smaller areas of irrigable land. A farm of this kind, when it can be had, utilizes to the best advantage the agricultural resources of the country. Even when no dry-farming land can be included because of the scanty rainfall or other causes, an irrigated farm combined with a fenced area of grazing land is well adapted to stock raising.

5. Water Supply.—The characteristic feature of the climate of the western states is its low rainfall. Over most of this extensive region the mean annual precipitation is less than 15 inches, and over large areas it is less than 10 inches. The exceptions to these low averages are to be found mainly in localities bordering the Pacific Ocean and on the higher ranges of mountains, which intercept moisture-laden winds and cause a heavier precipitation, usually in the form of snow, which, when lodged and compacted

in deep mountain gorges, forms a considerable part of the water supply for domestic, agricultural and other purposes during the late summer months. The rain gage, as used by the Weather Bureau, is familiar to most people and need not be described. Check measurements of snowfall may be made by cutting and removing a cylindrical column of new snow in some sheltered locality and by adding a known quantity of hot water to the sample taken, sufficient to melt it. When the snow is not melted, the ratio of 10 units of snow to 1 of water will give approximate results.

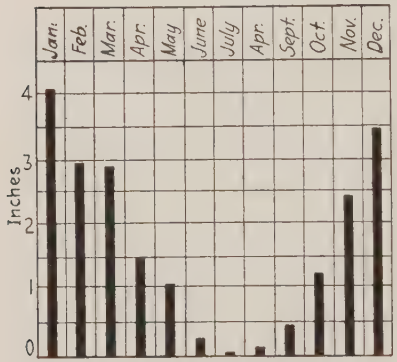


FIG. 2.—Average monthly rainfall, Sacramento Valley, California.

In common with other parts of the country, the rainfall of the West is not evenly distributed throughout the year. In most of the Rocky Mountain states the spring is the wettest season while in the Pacific Coast states the summers are dry and the winters

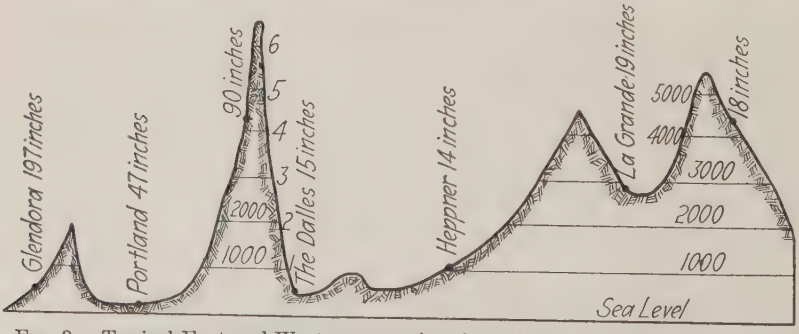


FIG. 3.—Typical East and West cross section through Northern Oregon, showing relation of annual rainfall with change of elevation.

wet. Some years ago, the writer averaged the rainfall records of 18 stations of the Sacramento Valley, California, with the result shown graphically in Fig. 2.[1]

[1] "Irrigation in the Sacramento Valley," *Bull.* 207, *O. E. S., U. S. Dept. Agr.*

The variation of rainfall within the boundaries of a state is shown in Fig. 3 which represents a cross-section through northern Oregon.[1]

The water used in irrigation is derived from streams, lakes, reservoirs, return flow, springs and wells. Table No. 8, taken from the report of the Fourteenth Census, gives the acreage irrigated in 1919 and 1909, classified by source of water supply, return waters being included in streams.

TABLE NO. 8.—ACREAGE, CLASSIFIED BY SOURCE OF WATER SUPPLY. 1919 AND 1909

Class	Area irrigated (acres)				Area enterprises were capable of irrigating in 1920, acres	Area included in enterprises 1920, acres
	1919	1909	Increase[1]			
			Amount	Per cent.		
Total	19,191,716	14,433,285	4,758,431	33.0	26,020,477	35,890,821
Streams, gravity	14,527,060	12,767,351	1,759,709	13.8	19,269,136	26,040,237
Streams, pumped	1,226,510	608,659	617,851	101.5	2,118,942	2,885,698
Streams, pumped and gravity	199,595	[2]	199,595	.....	237,700	284,353
Wells, pumped	1,263,098	489,341	773,757	158.1	1,674,819	2,356,748
Wells, flowing	65,856	144,420	−78,564	−54.4	79,777	131,137
Wells, flowing and pumped	35,685	[2]	35,685	.....	42,703	84,379
Lakes, pumped	35,730	17,826	17,904	100.4	59,760	80,564
Lakes, gravity	100,646	59,631	41,015	68.8	149,377	312,169
Springs	198,008	196,186	1,822	0.9	251,792	409,528
Stored storm water	98,873	105,792	−6,919	−6.5	223,434	319,972
City water	930	[2]	930	.....	1,401	1,666
Sewage	2,578	[2]	2,578	.....	3,301	5,540
Streams, gravity and pumped wells	344,713	[2]	344,713	.....	389,790	465,293
Streams, gravity and flowing wells	82,665	[2]	82,665	.....	104,569	205,121
Other mixed	996,621	44,079	952,542	.....	1,398,004	2,290,850
Other and not reported	13,148	[2]	13,148	.....	15,972	17,566

[1] A minus sign (−) denotes decrease. Per cent not shown when more than 1,000.
[2] Not included in classification.

Computing percentages from the preceding table, 83 per cent of the water used in irrigation in 1919 was derived from streams, lakes and springs, whereas 10 years prior over 94 per cent was derived from these sources. Notwithstanding the fact that the

[1] "Irrigation in Oregon," *Bull.* 209, *O. E. S., U. S. Dept. Agr.*

ratio between these sources and the total is diminishing, they yet constitute the bulk of the water supply for irrigation purposes and will continue to do so. It is becoming more and more difficult to ascertain the water yield of the stream basins of the West, however, for the reason that every new diversion adds to the difficulties. There was a time when the records of a stream-gaging station located above the intakes of irrigation systems represented the run-off of the basin above it. Now such records often possess little value by reason of the diversions above the gaging stations made for storage reservoirs, canals and pipe lines owned by power companies, irrigation enterprises, municipalities and others. The exchange of water between organizations and the return flow of streams still further complicate the problem. The need for reasonably accurate data pertaining to run-off is also becoming more urgent, since, in many localities, the smaller enterprises diverting water from a common source are being merged into one organization and it is becoming increasingly common to place all irrigation enterprises within a given stream basin under one control. The storage of flood waters is almost without exception a leading object in consolidations of this kind and for all the main purposes of such a knowledge of the monthly, seasonal and annual run-off is essential, particularly during dry years.

Where no stream records are available, or where it is desired to extend the estimate of run-off back of the earliest stream measurements, Scobey suggests the following means of making a percentage comparison with the rainfall as a basis:[1] Assume that Deer Creek has a watershed of 50 square miles, records of stream discharge for 7 years and precipitation records of 30 years. Also assume that Bear Creek, draining the adjoining area, has a watershed of 90 square miles, a measured run-off record of 15 years and an average precipitation record of 30 years. Now find the "index of wetness" for each of the 30 years for both Deer Creek and Bear Creek. This index is the rainfall for the year divided by the mean rainfall expressed in percentage. Thus if the average precipitation for all the stations on the watershed for all the years is 20 inches, and for any one year, as 1910, it is 25

[1] For further information on this subject, see *Bull.* 5, "Flow in California Streams," *Dept. of Pub. Works*, Sacramento, Calif.

inches, then the index of wetness for 1910 is 25/20 × 100 or 125 per cent. Make a diagram of the years of measured run-off record, platting the index of seasonal wetness as abscissas against depth of run-off for the same years, expressed in inches over the entire watershed, as ordinates. For Deer Creek this will give 7 points and for Bear Creek 15 points. Draw a smooth curve through Bear Creek plot, extending it to cover the greatest value "index of wetness." Using the 7 points and also noting shape of the Bear Creek curve, draw a similar curve for Deer Creek. Now from this curve take values of run-off in inches of water depth for each of the 30 values for the 30 years of precipitation record. This will give an approximate value of the water yield for each year in acre-feet when multiplied by the area of the watershed in acres and divided by 12 to reduce inches to feet.

It is believed that the storage of water is going to be the largest single factor in the agricultural development of the West during the next quarter of a century. This belief is based mainly on the following: The summer flow of most streams is over-appropriated. There is a wide difference between the normal and flood flow of streams occasioned by the melting of snow on mountain ranges or else by heavy rain storms. Present systems of irrigation were designed and built in most cases to use the summer flow of streams. There are far too many small systems taking water from a common source. The main incentive in remodelling old systems is to secure a more dependable water supply and to enlarge the area irrigated, but these objects cannot be attained unless by storage. Fully 40 per cent of the water supply of the West has been diverted but not wholly utilized, and most of the balance can be rendered available only through storage.

The return flow to stream beds and the reuse of water tend to increase with the extension of irrigation. Today return flow is an important factor on many streams and is so regarded by administrative officers charged with the duty of allotting water supplies. Some of the conditions affecting seepage and return waters are a liberal use of water, a rise of the ground water, proximity of the irrigated lands to the river, precipitation, porous soils and subsoils, porous and broken lava formations, broken limestone formations, temperature of material through which the water passes,

seepage from canals and reservoirs, absorption of flood water by banks and sand bars along the stream channel, topography, and other conditions.

The return flow of four streams has been investigated by the author or under his supervision. These were Weber River, Utah; Ogden River, Utah; Bitterroot River, Montana, and South Platte River, Colorado. The results of two of these are herein briefly summarized.

In a series[1] of measurements made on the Bitterroot River, Montana, in 1903, over a distance of 48 miles, the effect of infiltration into porous material during flood periods and the subsequent release of this temporary storage is shown. The measurements of June 11 to 15 taken when the river was in flood showed a loss of 1901 second-feet out of a total discharge at the lower end of the channel tested, including tributaries, of 12,974 second-feet. The second series was made July 9 to 14 and showed a gain of 439 second-feet out of a total of 4,383 second-feet. The third series was made August 7 to 14, at a time when the discharge of the river and the tributaries was low. At this time the total outflow was 1,649 second-feet and the gain in 48 miles was 1,114 second-feet.

The results of investigations made on the South Platte River between Kersey and Julesburg, Colorado, a distance of 143 miles, are shown graphically in Fig. 4.[2]

In recent times gravity water supplies have been augmented by water pumped from streams, wells and lakes. The 1919 census returns show that over 2,500,000 acres were irrigated with water pumped from these three sources, and that a partial supply was furnished to 580,000 acres; nearly half of this acreage was served with ground water pumped from wells.

The improvements that have been and are being made in pumping machinery, gasoline and other engines, and the extended use of electric power, coupled with the increasing cost of gravity supplies, have been the chief causes of this rapid development.

The waste water from irrigation is likewise augmenting the

[1] FORTIER, SAMUEL, "Irrigation in Montana," *Bull.* 172, *O. E. S., U. S. Dept. Agr.*

[2] Reproduced from *Bull.* 279, *Colo. Agr. Exp. Station*, "Return of Seepage Water to the Lower South Platte River," by RALPH L. PARSHALL.

available ground water. Seepage from earthen channels and deep percolation losses from irrigated areas greatly increase the supply in shallow underground reservoirs and tend to raise the water table to within economic lifts for pumping. As will be discussed under "drainage," pumping is resorted to in a number of localities to provide drainage by lowering the water table. The reverse of this process is effected in localities of scanty water supplies, replenishment of underground basins from which water is pumped being brought about by diverting flood waters and

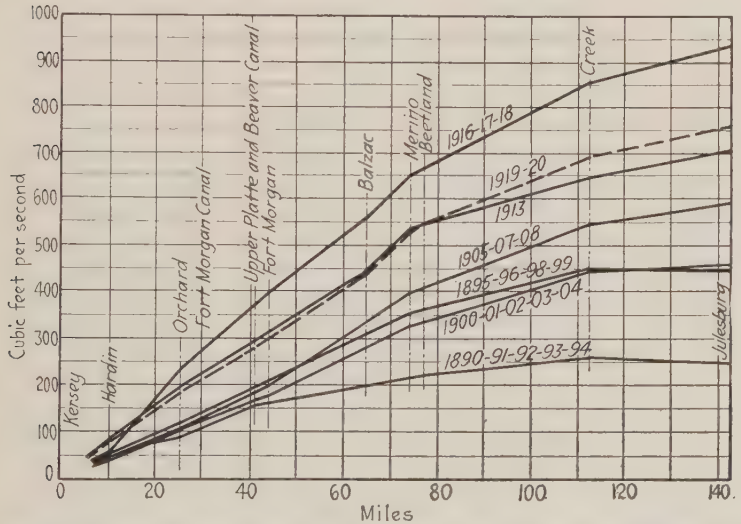


FIG. 4.—Curves showing the gain of return flow to the South Platte River from Kersey to Julesburg, Colo., for the various years from 1890 to 1920.

distributing them in cheap ways over the surface of such basins into which the greater part sinks.

Many of the earlier estimates of the extent of land that could be irrigated in the western states were far from accurate. About 35 years ago, when little was known of the stream flow, recognized authorities on such matters placed it at 130,000,000 acres. As stream records became available, this figure was reduced first to 100,000,000, then to 90,000,000, subsequently to 75,000,000 and finally to 65,000,000 acres. If the following estimates in Table No. 9 are not too conservative, even this last estimate is too high.

It is believed that these estimates represent about all the land that can be irrigated with the water available in the Pacific Coast and Rocky Mountain states. It is, however, more difficult to predict the extent of irrigation development that may take place in such states as Oklahoma and the Dakotas.

TABLE NO. 9

Name of state	Area of land surface within state, acres	Area for which water is available, acres	Area irrigated in 1919, acres	Authority
Arizona	72,838,400	1,000,000	467,565	R. H. Forbes
California	99,617 280	12,000,000	4,219,040	Frank Adams, F. C. Scobey, S. Fortier
Colorado	66,341,120	4,500,000	3,348,385	C. W. Beach and P. J. Preston
Idaho	53,346,560	4,750,000	2,488,806	W. G. Swendsen
Kansas	52,335,360	5,060,000	47,312	Geo. S. Knapp
Montana	93,568,640	6,500,000	1,681,729	Samuel Fortier
Nebraska	49,157,120	1,500,000	442,690	A. L. Fellows, S. Fortier
Nevada	70,285,440	1,052,000	561,447	J. C. Scrugham
New Mexico	78,401,920	1,560,000	538,377	L. A. Gillett
North Dakota	44,917,120	1,540,000	12,072	T. R. Atkinson
Oklahoma	44,424,960	500,000	2,969	Samuel Fortier
Oregon	61,188,480	3,000,000	986,162	Percy A. Cupper
South Dakota	49,195,520	750,000	100,682	Samuel Fortier
Texas	167,934,720	3,000,000	586,120	J. C. Nagle
Utah	52,597,760	2,000,000	1,371,651	G. F. McGonagle
Washington	42,775,040	3,113,000	575,400	Marvin Chase
Wyoming	62,460,160	6,200,000	1,207,982	C. T. Johnston
Total	1,171,385,600	57,725,000	18,638,389	

6. Water Rights.[1]—To safeguard the permanency of agriculture in the arid West, there has been evolved a system of customs and laws controlling the use of water under which farmers and other water users secure a "water right." Without such a right, arid land would have little value and the planter of an orchard or other perennial crop would have no assurance of getting water each season to supply the needs of the crop.

The right to divert and to use the waters of streams or other surface and underground water supplies for irrigation and like

[1] For further information on this subject, the reader is referred to *Bull.* 913, *U. S. Dept. Agr.*, "The Western Farmer's Water Right," by R. P. TEELE.

purposes, being under state control, is regulated by the constitutions, statutes and court decisions of the different western states, and although all agree in a few essential requirements, rather wide differences exist in some other respects.

One of the essentials is known as the right of appropriation. If water is available from any public source, it may be appropriated in accordance with the state regulations in effect governing such procedure.

Another feature common to most water rights is known as the doctrine of beneficial use. Actual use of the water appropriated is a necessary step in the holding of a right, and when the use ceases, the right after a fixed time is forfeited.

Still another essential is known as the doctrine of priority. Among users from the same source, the first in time is the first in right. When there is not enough water for all, the rights are granted to the extent of the supply available in the order of the dates on which they were acquired, and these dates relate back to the date of the first step taken to acquire them and not to the time when the water was first used.

In California, Nebraska, Oregon, Texas and Washington, there is some water used for irrigation under the common-law doctrine of riparian rights. A riparian right is a right to use water from a stream which flows through or borders the land to which the right belongs. Such rights cannot be lost by disuse and can be separated from the land only by specific grant. Strictly applied, the doctrine of riparian rights precludes the use of water for irrigation, and in consequence has been either abrogated or modified in all the arid states.

In Texas, and the states created out of the territory acquired from Mexico, there is some water used, the rights to which are based upon old Spanish or Mexican grants to individuals, companies, or pueblos, the old rights being recognized by treaties and laws of the United States and the states. These rights vary widely as under the civil law the water belonged to the crown and in making a grant any restrictions desired could be inserted in the grant.

Apart from the relatively small area of land irrigated under riparian rights and the still smaller area under Spanish and Mexican grants, the water rights for western lands have been

acquired by appropriation and use. The procedure in acquiring such rights in all western states except Kansas and Montana consists in the main in first making application to some state official, usually the State Engineer, on forms furnished for this purpose, giving the name and address of the applicant; the source and intended use of the water; the nature of the ditch or other works; maps showing the location and extent of the ditch; the location and area of the land to be irrigated; the dates when construction will begin and when the works will be completed and the water put to the intended use.

The application is examined to ascertain whether it is in proper form and complies with the laws and regulations, and if so, it is recorded and it is the duty of the State Engineer or state board to approve the application and issue the permit if there is unappropriated water in the source of supply, provided the proposed use will not impair the value of existing rights or be detrimental to the public welfare. The permit issued by the State Engineer or state board fixes the amount of water which may be appropriated, and its point of diversion; and the time within which the works must be begun and completed and the waters put to a beneficial use. Upon submission of proof that the conditions of the permit have been complied with, a certificate is issued by the state showing what rights have been acquired. About 17 per cent of the acreage irrigated in 1919 was irrigated under permits or certificates from the state, so small a percentage being due to the fact that the laws providing for this method of securing rights have been on the statute books in some cases for only a few years, the earliest, that of Wyoming, having been enacted in 1890, and the most recent, that of Washington, in 1917.

The states of Colorado, Kansas and Montana have not as yet adopted the more modern methods of acquiring water rights by appropriation, but may soon do so. In all three, the old mining custom of posting a notice at the point of diversion and recording with the county clerk the amount of water needed is still followed.

The purchaser of a tract of land with a water right should exercise the greatest care in determining the adequacy, reliability and validity of the water right. In making such examinations, it is difficult to arrive at correct conclusions, owing to the fluctuating character of stream flow, the various methods by which rights

may be acquired, the lack of records of existing rights, the claims that may be set up to destroy a right or change its priority, and the difficulty of securing proof of continuous use and compliance with laws regarding the appropriation of water.

Evidences of the rights to water direct from streams are represented by filings in county courts, filings in offices of State Engineers and state boards, and permits in these offices. The mere filing of a right does not give a valid title unless it is followed by construction of works and use of water. The same applies to permits issued by state officers. They merely fix the time within which the works must be begun and completed and the time within which the water must be put to a beneficial use.

In some states a special tribunal is created to investigate and settle water rights; in others the adjudication is performed by the courts. The former issues certificates; the latter, decrees. In certificates of water rights direct from streams or other sources issued by the state, the date of appropriation is fixed, and the point of diversion, the quantity of water, and the location of the land are described. Similar information is embodied in court decrees. Both certificates and decrees are conclusive evidence that the holders have rights to the quantities of water stated therein for use of the lands described, but neither carries any guarantee that there will be sufficient water in the source named to meet the requirements throughout the irrigation season.

Teele, in the publication previously referred to, states:

> Certificates or licenses representing rights acquired in accordance with permits issued by states and as the results of adjudications made by state boards or officials and based on surveys made and testimony collected by state officials are the best documentary evidence of the possession of rights which are likely to be supplied by streams in average years, since they are based on proof submitted to a state board or official whose duty it is to protect the public, and are usually issued after inspection by those officials; court decrees and certificates rank next; while permits from state boards or officials and copies of filings in county or state offices rank last.

Rights to water from underground sources are grouped from a legal standpoint into (1) percolating waters, (2) artesian water, (3) underground streams flowing in unknown and undefined

channels, and (4) underground streams flowing in known and defined channels. From a physical standpoint it is often difficult to determine to which group underground waters belong, and where doubt exists, the water is usually considered to belong to groups 1 and 3. As such it belongs to the overlying land and the owner has a right to withdraw all he can get for irrigation and other purposes.

When underground waters flow in a known and defined channel, they constitute part of the supply of some stream or other source of water, and are subject to the same laws and customs which govern the appropriation of water from surface supplies. In other words, the owner of land bordering a stream does not possess the right to pump water from a well on the banks of this stream if it can be shown that the pumped water is derived from the stream and belongs by right to prior appropriators.

In regard to artesian waters, the trend of court decisions throughout the western states seems to be that such waters are subject to the use of the owners of land overlying the artesian basin and each is entitled to a reasonable use of the common supply. In this respect rights to artesian water, as Teele remarks, are similar to riparian rights on streams—they are not fixed and definite but depend upon the total supply and the total demand by all owners of land overlying the basin.

So far water rights from streams and other natural sources have been discussed, but the majority of water users derive their rights to water from organizations dealing with water, such as cooperative water companies, irrigation districts, Carey Act companies, commercial companies, and the Federal government. These correspond to the middlemen in commercial pursuits in that they acquire their water rights wholesale, so to speak, from the state, and dispose of them to individual land owners under contracts, by-laws and regulations. Water rights from such organizations differ from those previously described in not having a priority feature as regards individual users, and in the practice of pro rating the total supply when a shortage occurs. Other minor differences likewise exist because of the nature of the organization. Thus, in cooperative or mutual water companies, water rights are represented by the share of stock held and each share of stock entitles its holder to a proportionate share of the

flow of the main canal rather than to any definite quantity. Under the laws creating irrigation districts, the water goes with the land, and each acre within the territorial limits of the district is entitled to its share of the total supply, whatever that happens to be.

The laws and court decisions of the western states are not in accord as regards the separate ownership of land and water. In Wyoming, for example, all water rights granted by the state for irrigation purposes are attached to definite tracts of land, and when it is desired to detach a right and transfer it to another tract, it can only be done by strict compliance with statutory laws and administrative regulations. Furthermore, if such a transfer is likely to inflict injury on the holders of other rights on the same stream, the application is reasonably certain to be denied. Utah represents the other extreme as regards appurtenance. The laws and court decisions of that state permit the sale and lease of irrigation water apart from the land which it irrigates. Thus, a man may own a large number of shares of water stock in a canal company without owning an acre of land, and he can sell or lease these shares as he may elect.

In practice, both theories in relation to this phase of water rights have their advantages and disadvantages. While it is generally conceded that attaching a water right to a definite tract of land is the safer and better public policy, the law should be sufficiently elastic to meet the requirements caused by changed physical conditions. The amount of water necessary to irrigate an acre of land is not a fixed quantity but changes with a score or more of changing conditions. Accordingly, it is far beyond the ability of any state or Federal official to attempt to fix for all time the maximum limit of the water supply for a farmer's water right. Cases might be cited where a second-foot of water has been required to irrigate 40 acres of land, and 20 years later, as a result of changed conditions, the same amount of water has served, with more profitable returns, 160 acres. Furthermore, a large percentage of irrigated lands, variously estimated at from 10 to 30 per cent., becomes water-logged through the use of too much water, and so long as a high water table prevails, the irrigation requirements are greatly lessened. These references, with others that might be named, show the need of granting ample

authority to state administrative officers to make adjustments as necessity demands rather than the fixing of a general and arbitrary figure in statutory enactments to represent the maximum amount of water per acre which can be used under all water rights granted by the state.

7. Soils.[1]—As the soil forms the only foundation upon which agriculture can be developed, it is deserving of special attention from the farmer, both in the selection of a farm and the manner in which it is subsequently cultivated and irrigated.

In an agricultural sense, the soil constitutes a very thin stratum upon the surface of the earth in which plants grow, or can be made to grow. The soil may be defined as a mass of finely divided rock material containing decaying vegetable or animal matter. Nearly all soil is derived by the breaking down of rock through the agencies of ice, running water, changing temperatures and wind. Soils which remain in the place of the rocks from which they were derived are known as residual soils. Soils which have been moved and deposited at a distance are known as transported soils. The transported soils are of far greater extent than are the soils of residual formation and of greater importance to the agriculturalist. The residual soils commonly retain some of the characteristics of the parent rocks. They commonly have more clay in the subsoils than in the surface soils, usually contain fragments of the partially decayed rock in the deeper subsoil, and are underlaid by the parent rock. The transported soils often bear no resemblance to the formations from which they were derived, but are commonly a heterogeneous mixture of material from a number of rock formations, and the soil particles have often undergone marked physical and chemical alterations. Recently formed transported soils occupy areas along streams, on low terraces or in overflow basins. They are prevailingly friable and porous, more or less stratified and, with minor exceptions, usually contain an abundant supply of the mineral elements required by plants. The older transported soils differ in both chemical and physical properties from those of recent formation. The soil particles show more advanced stages of weathering; the subsoils often contain more of the finer particles than the surface

[1] Extracted from an unpublished memorandum by A. T. Strahorn, Scientist in Soil Surveys, *Bur. of Soils, U. S. Dep. Agr.*

soils, due to a slow washing down of the silt and clay grains; and, through the leaching of soluble materials from the surface soil, compacted and cemented structures are often developed at varying depths below the surface. The older transported soils occupy high terraces, plains and alluvial fans above the present stream channels, and commonly possess an undulating to hummocky topography. Of less general importance—but often of very great local importance—are those soils formed by the growth of vegetation in bodies of slow-moving or stagnant water. The recurring growth and decay of tules, water grasses and similar vegetation, with the inclusion of sediments carried by the water, results in the development of what are known as "peat" or "muck" soils. Under the proper cultural methods, these soils form some of the most productive farming lands in the world.

Some system of classification must be developed for the intelligent and systematic study of any natural object in order that all of the conditions under which it occurs may be fully understood. Different systems have been used, from time to time, in the studies of soils depending upon the objects that different investigators have had in mind. Such classifications ordinarily have but limited application and in order to acquire the widest and most satisfactory knowledge of all phases of the soil, some system of classification must be adopted that will be broad enough to include all soils, and at the same time offer a foundation upon which the various lines of scientific and practical investigations can be carried on.

A comprehensive system for the classification of the soils of the United States has been developed by the Bureau of Soils, of the U. S. Department of Agriculture. The work of that organization has reached such a scope that the method of classification has become standard in this country. Briefly, the classification involves the division of the United States into a number of soil provinces and regions, with the recognition of a large number of soil series and soil types in each district. Soil provinces and regions take into consideration only the broader relations of soils with regard to origin, formation, physiography, and geologic and climatic features. The soil series groups all soils, in any division, having related features of origin, formation, color, structure, texture and physiography. The soil type is the unit of the

soil series and is based upon differences in the textures of the soils. The texture is determined by arbitrary percentages of the sizes of the soil particles that are present. Series are designated by names which, in so far as possible, identify each series with the locality in which it was first found, and the name is thereafter applied to any group of soils which conform to the specifications of the original series. Soil types are designated by the name of the series to which they belong and by a name which defines their textures. The Hanford fine sandyloam type, for example, is a soil of the Hanford series that has a fine sandyloam texture. The following table gives the mechanical analysis of a number of typical soils from irrigated valleys in the West.

TABLE No. 10

Class of soil and location	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
Millimeters	2–1	1–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.005	0.005–0
Salt River clay loam, Ariz.	Tr.	0.12	0.20	3.80	12.78	42.30	41.00
Imperial fine sand, Calif.	0.00	Tr.	1.20	42.20	38.00	15.00	3.58
Imperial clay loam, Calif.	Tr.	0.30	0.34	1.92	3.64	53.90	39.80
San Joaquin Valley sandy loam, Calif.	1.60	13.40	13.70	27.10	11.90	21.00	10.90
San Luis sandy loam, Colo.	8.96	22.08	10.26	15.54	11.70	19.84	11.26
Bozeman silt loam, Mont.	0.20	0.70	0.50	1.40	8.10	71.30	17.80
Finney fine sandy loam, Nebr.	0.10	0.30	0.30	10.00	48.60	35.10	5.50
Lahontan sandy loam, Nev.	3.60	10.30	13.60	30.60	18.60	14.20	9.40
Morton loam, S. Dak.	0.20	0.10	1.10	16.00	20.70	39.10	22.40
Amarillo sandy loam, Tex.	0.40	7.90	18.50	44.20	13.30	11.00	7.90
Jordan loam, Utah	0.36	0.90	0.60	2.24	14.64	43.08	37.80
Yakima sandy loam, Wash.	1.50	3.08	2.06	5.96	34.82	45.04	3.98
Quincy silt loam, Wash.	0.00	0.50	1.30	9.30	32.60	51.80	4.40

The climatic conditions under which soils develop exert very marked effects upon both the chemical and physical features of the soil. In soils developed under humid conditions, the chemical agencies have predominated, and the soluble materials have been rather thoroughly leached out and the soil particles are often in advanced stages of decomposition. In arid regions the mechanical agencies of soil formation have been more pronounced

and the soil particles show but little weathering; there has been but little leaching of the soluble substances, and much of the products of weathering remain adherent to the soil grains and available for the use of plants when the soil is placed under irrigation. Chemical analyses of soils from humid and arid regions show that the soils of the latter region contain larger quantities of lime, potash and phosphoric acid than do the humid soils, but that the amount of organic matter is lower. This latter condition is partly offset by the fact that the nitrogen content of the humus is considerably higher in arid soils.

The physical differences between humid and arid soils are striking features. In arid regions, the physical forces of soil formation, rather than the chemical agencies, dominate and give rise to prevailingly coarse-textured soils that are usually permeable to great depths. The relatively impervious clay subsoil of the humid regions is usually lacking, but there is often the occurrence of "hardpans" in the arid soils. This condition is due to the leaching out of portions of the soluble materials from the surface soils and their redeposition about the soil grains at depths to which the rainfall penetrates. Hardpans tend to prevent deep percolation and by retaining the moisture often make successful dry-farming operations possible over extended areas. Under irrigation, the hardpan is frequently broken up by blasting in order to establish satisfactory drainage conditions and to make room for the roots of plants.

Alkali is a feature of soils developed under conditions of low rainfall. Alkali is simply the soluble products which were developed during the processes of soil formation and which were not removed from the soil by leaching. In arid soils having satisfactory subsurface drainage conditions, these soluble materials are not present in large amounts, but when the drainage conditions are not adequate, they become concentrated and injurious to plant growth. Such conditions may be observed throughout the West wherever the natural drainage conditions have been deficient or where irrigation has developed swampy and seeped areas of land.

Too much care cannot be exercised in the selection of land for irrigation in the arid regions. This applies not alone to the settler who has had previous experience under such conditions,

but it applies with particular force both to the inexperienced man and to the one whose farming experience has been confined to regions of sufficient rainfall. The depth of the soil should be critically examined to make certain of a sufficient depth for crops and to insure adequate drainage. The subsoils should be neither too compact and impervious nor too porous and leachy. Impervious subsoils are not particularly detrimental, providing they are not so thick that the cost of breaking them up is prohibitive. Excessively coarse-textured subsoils are not desirable since it is difficult to maintain satisfactory moisture conditions in them, an excessive amount of irrigation water may be required, the yields of crops may not be as satisfactory as upon soils of finer texture, and the irrigation of such soils may result in the water-logging of adjacent lands. Drainage conditions should be carefully considered, not only as to the tract itself, but as to its situation with regard to canals and other irrigated tracts. Seepage may develop through the banks of canals and the productivity of the land be materially reduced. Seepage conditions may arise from the irrigation of adjacent lands either because the latter are of a greater elevation or because they are lacking in good natural drainage. The topograpy should be noted, as the cost of leveling the land will depend upon the smoothness and steepness of the slope. Steeply sloping surfaces are difficult to irrigate and should, in general, be avoided. Alkali lands should be viewed with suspicion. Such lands may usually be made productive through the operation of drains, but the costs of drainage may prove a heavy burden. The full productivity of the land may, also, not be secured for a period of years. Whenever alkali is present in the soil in amounts dangerous to the growth of crops, its presence is evidenced either by incrustations of salts upon the surface; thin stands of cultivated crops; or by the presence of alkali-tolerant vegetation.

When a selection of a tract of land has been made, after giving due consideration to the soil and drainage conditions, the varieties of crops to be grown, the cultural methods, and the use of irrigation water should conform to the conditions which experience has shown as best suited to the region. This applies with particular emphasis to the settler accustomed to farming without irrigation. Much of his former experience will be of little value

and his success will depend largely upon his readiness to apply the methods that have been found satisfactory.

8. The Root Systems of Plants.—That part of farm crops which function in the soil has not been investigated with the same care and thoroughness as that which is above ground. The roots are hidden beneath the surface, and cannot well be removed for observational purposes without affecting the normal life of the plant. This difficulty from an investigator's standpoint has caused the field to be shunned, and accounts in part at least for the dearth of information on the subject. Another reason for neglecting this study has been involved in climatic and soil conditions. Plants have been studied mainly under humid conditions where soil moisture depends upon rainfall and is for the most part beyond the control of the husbandman. Besides, under humid conditions the soil is shallow, and the subsoil infertile. There seemed, therefore, little to be gained in ascertaining the close relationship between soil moisture and roots. On the contrary, under arid conditions where water is artificially applied, a knowledge of root systems has become indispensable. Irrigation farmers are beginning to realize that if the soil moisture within the root zone of plants is to be sufficient in quantity and kept under proper control, the location of the roots both as to depth and lateral spread should be reasonably well known in order to confine the water applied in irrigation to the feeding ground of the plants. They also realize that the profits derived from irrigation farming depend in no small degree upon the proper development of the root system; the larger the feeding ground, the better the opportunity to secure food and water for the plant. It has also been demonstrated by McLaughlin[1] and others that capillarity cannot be depended upon to supply all the moisture needed by vigorous plants, which must have their necessities in this regard satisfied by an extension of the roots to where water can be had. This last furnishes an additional reason for deep rooting and more definite information regarding the location of roots.

The depth and lateral spread of the plant roots depend primarily on the kind of plant grown and the character of the soil

[1] McLaughlin, W. W., "Capillary Movement of Soil Moisture," *Bull.* 835, *U. S. Dept. Agr.*

and subsoil. The moisture content, fertility, location of water table, nature and depth of cultivation and the like may be said to exert secondary influences. Apart from anchoring the plant in the soil, the main function performed by the root system is to withdraw from the moisture in the soil the large amount of water required by the plant, and, dissolved in this water, the food necessary for its growth. If both water and food can be readily procured near the surface, as often happens in frequently irrigated

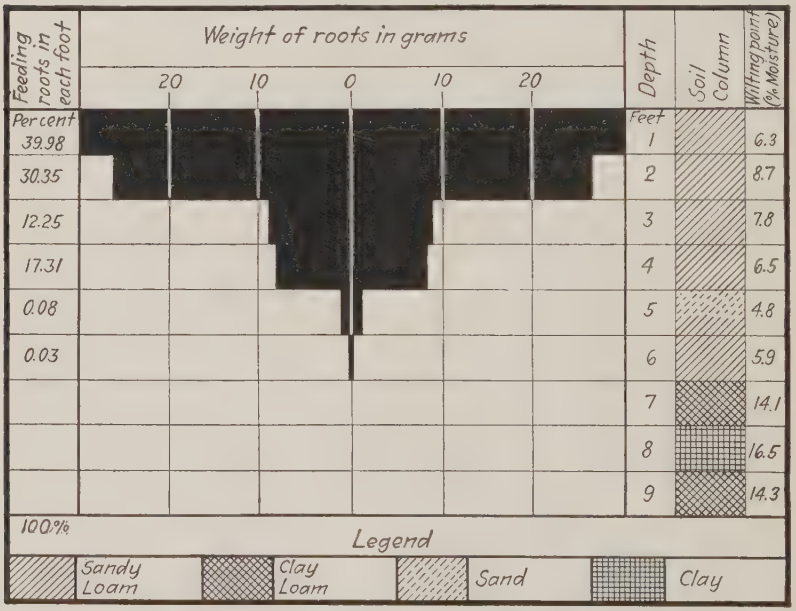


FIG. 5.—Distribution of feeding roots of alfalfa in fine sandy loam soil in Imperial Valley, California. No water table within 15 feet of ground surface.

rich soil, shallow rooting is encouraged, but when the top layer of soil contains little moisture, and the wetter soil lies beneath, roots will seek the wetter soil, and this results in deeper rooting. In other words, with the moisture content more or less under control, as it is in irrigation farming, it is possible to control somewhat, in turn, the depth, and to a less extent the lateral extension of the root system. Sometimes a water table is formed beneath the surface, and, when its level rises into the root zone and remains there, it kills the deeper roots in time, and in this

way creates a shallow-rooted system. The effect of soil moisture and also of a water table on alfalfa roots reproduced from Pack-

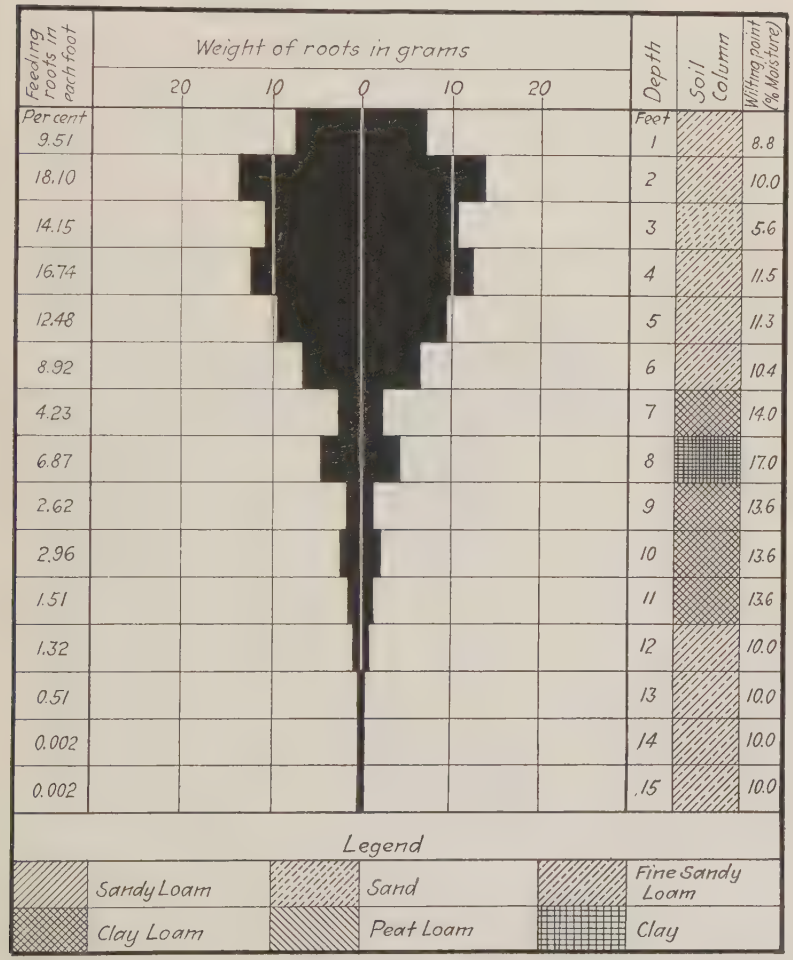


FIG. 6.—Distribution of feeding roots of alfalfa in sandy loam soil in Imperial Valley, California. Saturation at 15 feet. Infrequent but heavy irrigation.

ard[1] are shown in Figs. 5 to 7 inclusive. Figure 5 shows the distribution by weight of alfalfa roots in fine sandy loam in Imperial

[1] PACKARD, WALTER E., "Irrigation of Alfalfa in Imperial Valley," *Bull.* 284, *Univ. of Calif.*

Valley, California, where there was no water table within 15 feet of the ground surface. The alfalfa was 9 years old, and the field produced from 6 to 9 tons per acre in six cuttings. It will be noted that the largest quantity of roots is in the second foot, and that 95 per cent is in the upper 4 feet.

Figure 6 shows the effect produced in the distribution of alfalfa roots by scanty surface irrigation and the presence of a water table 15 feet below the surface, from which latter source a part of the water needed by the plant was derived.

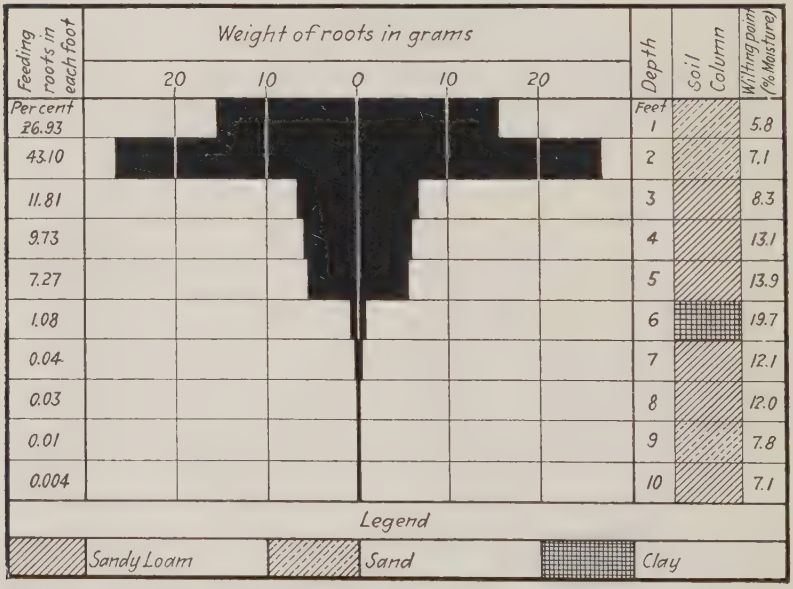


FIG. 7.—Distribution of feeding roots of alfalfa in sandy loam soil in Imperial Valley, California. Water table at 4½ feet below ground surface.

In Fig. 7, the roots have been forced nearer the surface by the presence of a water table about 4 feet below the surface. In this case 40 per cent of the roots are found in the first foot, and over 30 per cent in the second foot, with practically none in the fifth foot, because of the presence of standing water.

An examination of the foregoing charts reveals some of the difficulties to be met in attempting to locate the roots of plants. In friable soils having a plentiful supply of water in the lower

strata, a certain percentage of the root system will be deep rooted, especially if the top layer of soil contains little moisture. This will be true of shallow-rooted plants in order to safeguard their existence during droughts. On the contrary, in irrigated soil having the moisture content in the second, third and fourth foot maintained well above the wilting point, the bulk of the roots will be found in these top layers. The object of the irrigator should be to maintain as far as practicable an ample supply of moisture from the base of the dry earth mulch to the bottom of the third foot or so, and to leave to the action of gravity and capillarity the task of keeping the lower strata moistened.

Dr. E. C. Miller, of the Kansas Agricultural Experiment Station, has taken a leading part in recent years in the investigation of the root systems of such plants as corn and sorghums, and since his experiments were conducted in western Kansas the results possess a high value to the people of arid America. In the case of dwarf milo, kaffir and corn, Miller found that the average ratio of the weight of stems, leaves and grain to the weight of roots ran very close to 15 to 1.

Schulze made similar experiments with other plants. Table No. 11 gives a summary of both records.

Table No. 11.—Maximum Depth of Roots, Weights of Aerial Parts and Roots and Ratio of Tops to Roots

Plant	Maximum depth of roots, feet	Weight of aerial parts, grams	Weight of roots, grams	Ratio of weight of tops to roots	Authority
Wheat	6.1	31.4	2.9	10.8	Schulze, 1906
Barley	5.8	27.8	2.1	13.5	Schulze, 1906
Oats	7.6	45.4	4.1	11.1	Schulze, 1906
Milo	6.8	197.4	12.6	15.7	Miller, 1915
Kaffir	8.8	304.5	20.5	14.9	Miller, 1915

From the point of view of the western irrigator the essential features thus far known in regard to roots and root systems may be summed up in the following:

1. Compared with soils formed under humid conditions, arid and semiarid soils are deeper, more porous, better aerated,

and contain a larger percentage of mineral plant food. Accordingly, the roots of plants grown in western soils occupy a larger zone, especially as to depth, and constitute a larger percentage of the total weight of the plant.

2. Throughout most of the western states, the evaporation of moisture in midsummer from the top layer of moist soil is excessive, and not infrequently reduces the moisture content in the upper 6 to 12 inches below the wilting point. To prevent the growth and subsequent immature death of roots in this layer, deep tillage should be practised in cultivated crops, and in all cases an abundant supply of moisture maintained throughout the lower strata of soil in order to bring about deep rooting and more stable soil-moisture conditions.

3. Other conditions being similar, the more fertile and deeper the soil the greater the root development and penetration, thus enabling the plant better to withstand the effects of drought.

4. A medium soil-moisture content will produce a larger root development than a high water content.

5. The rate of root growth is greatest during the first 15 to 20 days after the germination of the seed.

6. While the bulk of the roots of plants including citrus and deciduous orchard trees are to be found in the upper 4 feet of soil, a certain percentage of the roots of most plants extend to greater depths, and maximum production seems to depend on the presence of these deep roots to furnish additional water and food.

7. To permit the growth and proper functioning of the deep roots referred to in No. 6, shallow soil should not be selected, and if cropped, the most suitable means should be used to break up the plow sole and hard pan by deep cultivation or blasting or both. Similarly, when the water table rises within the root zone, drainage should be resorted to in order that the deep roots may have a chance to develop to their fullest extent.

9. Soil Water.—"The water of the earth," says Meinzer[1] "can be divided into three parts—that which occurs in the atmosphere, that which rests on the surface of the solid part of the earth and that which occurs below the surface." The divisions of subsurface water of most service to the farmer, and more

[1] Meinzer, Oscar E., "Outline of Ground-water Hydrology," *Water Supply Paper* 494, *U. S. Geol. Survey.*

particularly the irrigation farmer, are soil water, well water, springs, artesian water, the underflow of stream channels, seepage water and the storage of water in underground basins.

Soil water is classified as hygroscopic, capillary and gravitational. Hygroscopic water is the water in the soil that is in equilibrium with atmospheric water vapor. "It is essentially," says Meinzer, "the water which molecular attraction can hold against evaporation."

The smaller the particles of soil, the greater is the surface area of a unit volume and the greater the quantity of hygroscopic water held by it. Loughridge found that sandy soils contained 1 to 3 per cent of hygroscopic water, loam soils about 5 per cent and clay soils 7 to 10 per cent.

The significance of hygroscopic water in connection with plant growth is summarized thus by Hilgard:

1. Soils of high hygroscopic power can withdraw from moist air enough moisture to be of material help in sustaining the life of vegetation in rainless summers, or in time of drought. It cannot, however, maintain normal growth save in the case of some desert plants.
2. High moisture absorption prevents the rapid and undue heating of the surface soil to the danger point and thus often saves crops that are lost in soils of low hygroscopic power.

Capillary water being variable is difficult to define, but in general it is the film of water surrounding soil particles whose movement is retarded by surface tension against the direct action of gravity.

Gravitational water, as its name implies, is that which is drawn downward by gravity through soils with comparative freedom of movement.

It was formerly held that capillary water was not affected by gravity but McLaughlin has disproved this theory. It was also held that plants received all their moisture supply from capillary water, but Alway, Batchelor, and Reed have shown that under severe drought conditions the life of some plants may be sustained by hygroscopic water. It is likewise true that plants absorb gravitational water. Accordingly, in attempting to define usable soil water or the water which plants can use, it may be said that it includes all capillary water, some gravitational water and less often some hygroscopic water.

In studies of the relation of soil water to plant growth, several expressions are frequently used which will be briefly defined.

The hygroscopic coefficient of a soil expressed as a percentage is $100 \times h/w$, where h is the weight of the hygroscopic water, and w the weight of the soil when dry.

The wilting coefficient is the percentage of moisture in the soil when plants growing therein become permanently wilted, and may be expressed as $100 \times d/w$, where d is the weight of water in the soil when permanent wilting begins and w is the weight of the soil when dry.

The moisture equivalent is the percentage of moisture retained in a sample of soil after it has been subjected to a centrifugal force equal to 1,000 times that of gravity. It may be expressed as $100 \times c/w$, where c is the weight of the water that remains in the soil after it has been centrifuged, and w is the weight of the soil when dry.

When all interstitial space in soils is filled with water, it is said to be saturated.

The effective water-holding capacity of a soil is the percentage of water it can retain, but not indefinitely, in opposition to the force of gravity when free drainage is provided.

Formerly, augers of various kinds were used to take samples of soil for moisture determinations. The difficulty experienced in retaining and collecting the core of soil removed by an auger, and other defects of this device, led to the substitution of the soil tube, which is now generally used to sample all but the coarser soils. A drawing of a soil tube is shown in Fig. 8.[1] Such a tube not only collects the entire core removed, which is highly desirable if comparable results are to be obtained, but the moisture content of wet soils so sampled is usually larger than where augers are used.

On account of the variable character of soils and subsoils, care should be exercised in selecting locations for borings. Veihmeyer[2] cites a case where a series of five soil samples was taken to a depth of 6 feet at equidistant points of 8 feet around the

[1] Designed by F. J. Veihmeyer of the University of California in cooperation with W. W. McLaughlin of the Division of Agricultural Engineering of the U. S. Dept. of Agr.

[2] "Some Factors Affecting the Irrigation Requirements of Deciduous Orchards," unpublished paper by F. J. Veihmeyer.

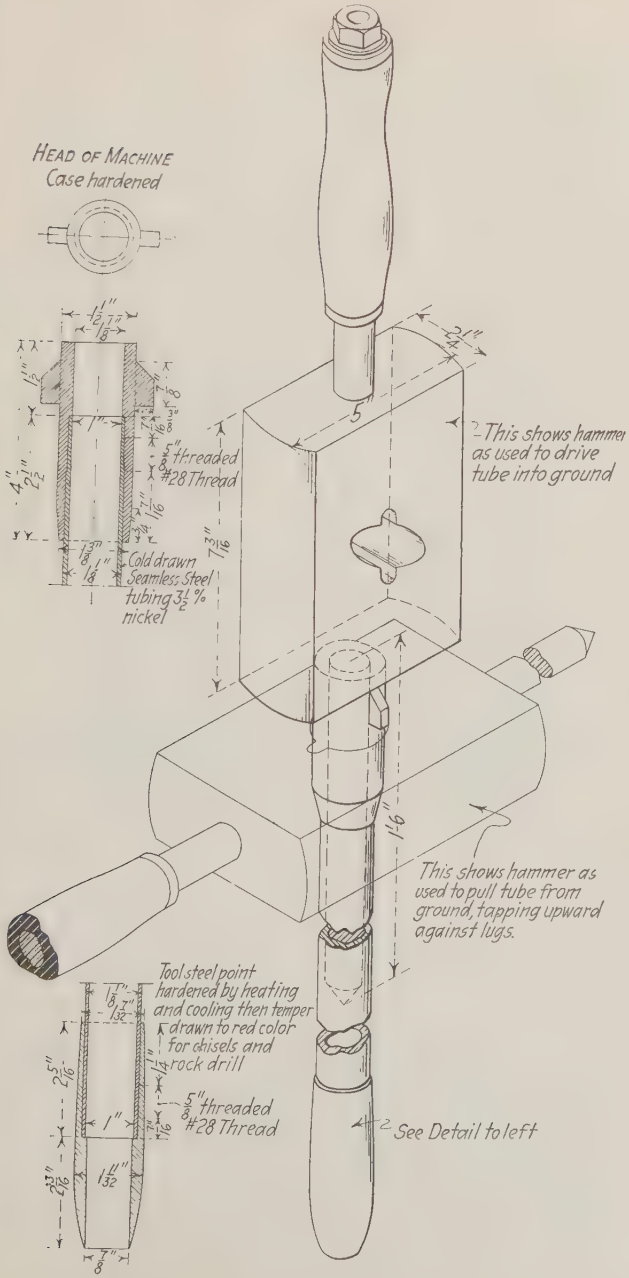

HEAD OF MACHINE
Case hardened
Cold drawn Seamless Steel tubing 3½% nickel
5/8" threaded #28 Thread
This shows hammer as used to drive tube into ground
This shows hammer as used to pull tube from ground, tapping upward against lugs.
Tool steel point hardened by heating and cooling then temper drawn to red color for chisels and rock drill
5/8" threaded #28 Thread
See Detail to left

FIG. 8.—Soil tube and hammer.

trunk of a peach tree growing in a fine sandy loam soil in Santa Clara Valley, California. Moisture conditions at the time the samples were taken were fairly stable, since no irrigation water had been applied that season, and the last rainfall had occurred about a month previous. The moisture content of the five samples in percentages of dry weight of soil were: 9.4, 11.0, 14.0, 15.1 and 16.3.

Such variations may be regarded as exceptional, and were doubtless caused mainly by the extraction of moisture by certain groups of roots, rather than by the difference in soil type. Never-

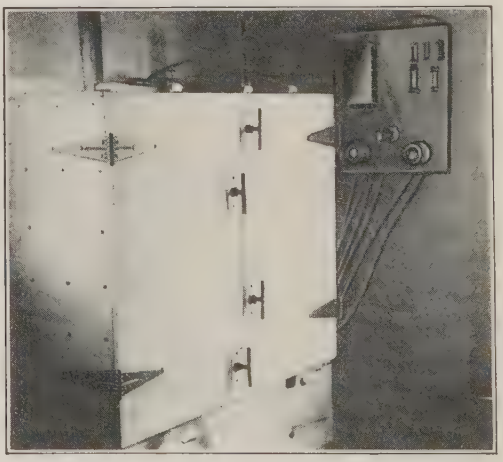


FIG. 9.—Electric oven for baking soil.

theless, all who have had a wide experience in sampling soils have met with marked differences in moisture content due to variation in soil type in even a small field. To lessen these differences, it is advisable to select and locate small areas, such as a square yard in the plot or field to be tested, and confine all samples taken in any one season to these locations.

Soil samples are placed in suitable cans which are placed in an oven and subjected to a heat of 105° to 110°C. until all the moisture is vaporized. An electric oven designed and built by Don H. Bark, when working under the author, at the subexperiment station at Twin Falls, Idaho, is shown in Fig. 9. The oven is made of 1/2-inch asbestos boards fastened together with

galvanized angle iron and stove bolts. It contains five shelves, has a capacity of 220 soil cans, and is heated electrically under thermostatic automatic control, so as to provide a range of temperature of 105° to 110°C. Ventilation holes controlled by discs are made in the top and bottom, and two thermometers are suspended from the ceiling of the oven. Similar ovens can now be supplied by firms dealing in laboratory equipment.

A determination of the total content of moisture in soil by the method just described is both laborious and costly. Besides, additional determinations are necessary to ascertain the percentage of the total moisture content available for plants. In other words, the amount of moisture in any given type of soil, when plants growing therein begin to wilt and fail to recover, must be deducted from the total moisture content in order to determine the available moisture. Several investigators have attempted to devise simpler methods of obtaining these results, and the one most commonly used is the centrifuge developed by Briggs and McLane of the U. S. Department of Agriculture. As stated, the percentage of water retained in a sample of soil when subjected to a centrifugal force of 1,000 times that of gravity was called the moisture equivalent. The moisture equivalent for different types of soil ranges from less than 2 per cent in the coarser sandy soils to 48 per cent or more in heavy clay soils, and these values when divided by 1.84 represent with a fair degree of accuracy the wilting coefficient.

Recent investigations carried on cooperatively between the University of California and the U. S. Division of Agricultural Engineering have shown that the moisture equivalent as determined by the centrifuge is liable to give inaccurate results, and the recommendation is made that the methods be further standardized in order to secure comparable results. Messrs. Veihmeyer, Israelsen, and Conrad, who investigated the operation of the centrifuge, found among other things: (*a*) that the amount of soil used influenced the results; (*b*) that the smaller the sample, the larger the percentage of moisture retained; (*c*) in the use of 5-, 10-, 20- and 30-gram samples, the placing of weights on the inner surface decreases the amount of water retained by the soil; (*d*) when precision is desired, it is necessary to measure the sample by weight rather than by the measuring cup; and (*e*)

that the variation in moisture equivalent with samples of different volumes or weights is influenced by the degree of compactness as well as by the depth of sample in the centrifuge cup.

From the viewpoint of the irrigation farmer, the two most important properties of soil as regards moisture are, first, the wilting percentage, and second, the effective water-holding capacity. These indicate the lowest and highest limits of usable soil water. The task of the grower is to prevent, on the one hand, the depletion of soil water below the point when plants will receive a permanent setback, and, on the other, to find out how much water soils will retain against gravity, so as to avoid overirrigation as well as underirrigation. The former may lessen the yield and

FIG. 10.—Basin in virgin soil in Jackson County, Oregon.

the latter results in waste of water. When the centrifuge is so standardized as to give reliable results, it will afford a ready and cheap method of determining the moisture equivalent and the wilting point of soils. The method practised by the Division of Agricultural Engineering of the U. S. Department of Agriculture in determining the effective water-holding capacity of soils is as follows: If procurable, virgin soil is selected, and a square surface containing about 100 square feet is diked by borrowing the material from outside so as to retain a depth of 12 to 15 inches of water in the basin. Such a basin is shown in Fig. 10, located on virgin soil partly covered by Pacific post oak in Jackson

County, Oregon. Soil samples for each foot to a depth of 6 feet are then taken in at least three holes in the basin to determine the initial moisture content, after which water is turned in and the basin filled. The rate of water sinkage is then recorded, and when all the water is absorbed, another series of soil samples is taken to determine the effective water-holding capacity. Water is not readily absorbed by heavy clay soils, and in dealing with this type, a second application of water may be necessary. Soil sampling subsequent to the time when all the water is absorbed is usually done at the end of scheduled periods such as 1 day, 2 days, 4 days and 8 days. These reveal the behavior of the water applied under the action of such forces as evaporation, gravity and capillarity.

10. Movement of Soil Water.—In a humid region, the moisture in the atmosphere is the main source of soil water. This moisture when condensed falls as rain or snow with fair uniformity over the surface of the ground. In an arid region with its low rainfall and high evaporation, the main source of soil water is the irrigation canal which delivers water to secondary canals and these in turn to small supply ditches which moisten fields and orchards. When a soil is irrigated, part of the water so applied is evaporated. As will be discussed later, the loss of water by evaporation is usually heavy for a period of 24 to 48 hours after an irrigation, and while the top layer of the soil is wet. The remaining part under skilful irrigation practice is stored mainly in the soil for the use of plants. Soil storage is temporary, however, since the action of gravity tends to deplete the moisture content to the hygroscopic limit. Thus the water absorbed by the roots of plants and transpired by their foliage, coupled with the withdrawal of water from the root zone by gravity and capillarity, necessitate periodic irrigations. Under liberal uses of water or careless practice more water may be applied than can be retained by the soil within the root zone of plants, and the excess known as deep percolating water moves through the subsoil until it encounters ground water or an impervious stratum along which it slowly moves on the natural grade until a depression is reached where the water-logging of soil may occur.

The movement of soil water is due to the action of gravity and capillarity acting in unison or otherwise. When water is drawn

vertically downward through soil, these forces act together. When water is drawn vertically upward through soil by capillarity it is done in opposition to the force of gravity. In the past and until recent years, the part performed by capillarity in distributing water through soil and in furnishing water to the rootlets of plants has been underrated where the source of supply is a free body of water, and greatly overrated where the source of

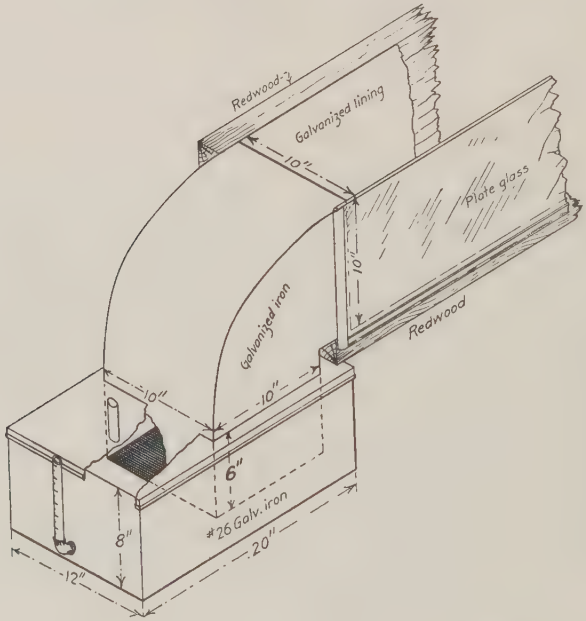


FIG. 11.—Device used in capillarity experiments.

supply was a body of moist soil. In regard to the latter it was formerly believed that the capillary water of soils could be readily drawn upward by capillarity in sufficient amounts and with sufficient rapidity to nourish plant life. The recent works of a number of investigators cast doubt on this performance. The experiments[1] by W. W. McLaughlin, begun in 1915 and continued for a number of years, are summarized herein as being the most conclusive in respect to the capillary movement of soil moisture.

[1] McLAUGHLIN, W. W., "Capillary Movement of Soil Moisture," *Bull.* 835, *U. S. Dept. of Agr.*, and "The Capillary Distribution of Moisture in Columns of Small Cross-section," *Bull.* 1221, *U. S. Dept. of Agr.*

The rate and extent of the movement of soil moisture by capillarity differ materially where the source of moisture is a body of free water from where it is a body of wet soil. Accordingly, McLaughlin's experiments were divided into two more or less distinct groups depending on the source of water supply. The essential part of the equipment used where free water was the source of supply is shown in Fig. 11. This consists of three main parts: (*a*) an iron tank in which water is maintained at a fixed level, (*b*) an iron elbow connecting the tank with a flume and retaining the soil by means of a sheet of brass-wire gauze in contact with the water in the tank, and (*c*) a flume of redwood lumber open or

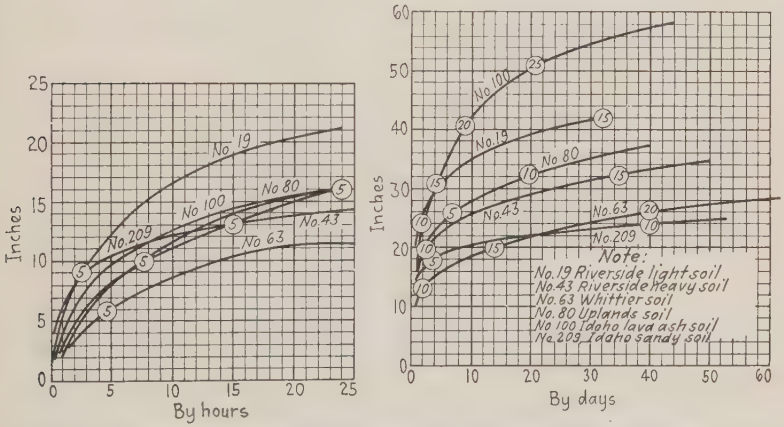


FIG. 12.—Rate of movement of moisture in vertical columns of soil. The numbers within circles and their location indicate the points at which those number of liters of water had been taken up.

closed on top, lined with thin sheet metal and having one side of plate glass. Great care was exercised in filling the flume and elbow with soil of a known type. The glass side permitted observations to be made of the rate of advance of the capillary water, and by varying the form of the angle the flume could be placed in different directions. The flumes were 10 by 10 inches in cross-section, and of various lengths. Below are listed the flumes placed for experimental purposes in a vertically upward position and the kind of soil placed in each.

Flume 100 contained the fertile and highly productive lava soil of central Idaho, having a moisture equivalent of 18.3 per cent.

Flume 19, a coarse decomposed granite soil from Riverside, Calif., having a moisture equivalent of 7.9 per cent.

Flume 80, a gravel soil from Uplands, Calif., having a moisture equivalent of 6.6 per cent.

Flume 43, a Ramona loam soil from Riverside, Calif., having a moisture equivalent of 14.1 per cent.

Flume 63, a heavy clay soil from Whittier, Calif., having a moisture equivalent of 38.3 per cent.

Flume 209 contained a sandy soil from central Idaho, having a moisture equivalent of 4.7 per cent.

Figure 12 shows the rate of movement of soil water in these various flumes during periods of 30 to 60 days. Converting liters and an area of 100 square inches into acre-inches per acre gives the results shown in Table No. 12.

TABLE NO. 12

Number of days	Types of soil and number of flume					
	Lava soil (100), acre-inches	Coarse granite soil (19), acre-inches	Gravel soil (80), acre-inches	Loam soil (43), acre-inches	Heavy clay soil (63), acre-inches	Sandy soil (209), acre-inches
1	4.88	5.49	2.44	4.27	4.88	2.59
2	6.71	6.10	3.05	6.10	6.10	2.74
3	8.54	6.71	4.27	6.45	6.71	2.82
4	9.72	6.86	4.47	6.71	7.32	2.89
10	12.81	7.78	5.49	7.42	9.00	....
15	14.34	8.24	5.86	8.08	10.62	....
20	14.95	8.62	6.24	8.54	11.35	....
30	16.17	9.06	7.17	9.36	12.21	3.36
40	17.39	9.31	7.48	9.70	12.57	....
50	18.37	....	....	10.00	13.06	3.86
60	.....	....	....	.....	13.42	....

A similar set of six flumes filled with soils of different types were placed in a horizontal position. The number of each of these flumes and the type of soil placed therein are given below:

Flume 20, coarse decomposed granite soil from Riverside, Calif.

Flume 31, Ramona loam soil from Riverside, Calif.

Flume 50, heavy clay soil from Whittier, Calif.
Flume 70, sand and gravel wash from Uplands, Calif.
Flume 90, lava soil from central Idaho.
Flume 200, sandy soil from central Idaho.

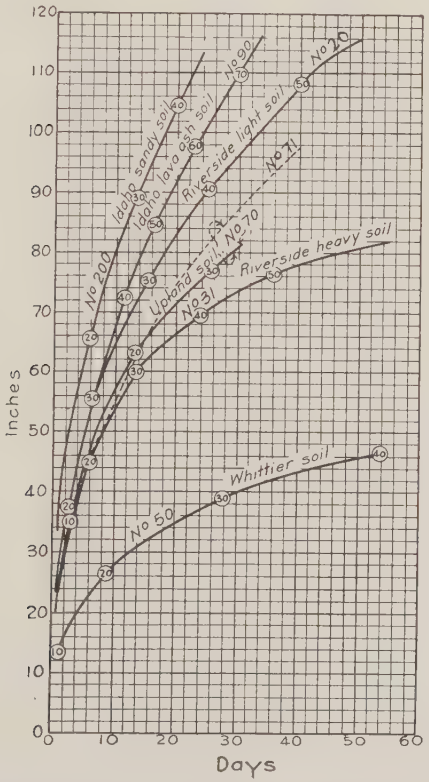


FIG. 13.—Rate of movement of moisture in horizontal open flumes. Figures in circles indicate points at which those numbers of liters of water had been taken up. The dotted line for flume No. 70 (curved) is for comparison with flume No. 70 open.

The rate of movement of soil moisture in horizontal open flumes from 25 to 56 days is shown in Fig. 13, and Table No. 13 gives the number of acre-inches of water per acre moved in a given time in each flume.

TABLE No. 13

Number of days	Coarse granite soil (20), acre-inches	Loam soil (31), acre-inches	Heavy clay soil (50), acre-inches	Sand and gravel wash (70), acre-inches	Lava soil (90), acre-inches	Sandy soil (200), acre-inches
1	4.58	6.10	4.88	3.67	7.32	6.10
3	7.93	9.76	7.93	6.10	12.21	9.15
5	10.07	11.59	10.76	7.34	15.87	11.59
10	14.34	15.87	12.81	10.37	22.58	15.25
15	18.00	18.22	14.95	12.82	28.68	19.53
20	21.82	22.27	16.48	15.87	34.78	24.40
30	26.85	27.46	19.12	20.14	42.72	.....

Another set of six flumes listed below was inclined downward at 30-degree angles.

Flume 4 contained a coarse granite soil from Riverside, Calif.
Flume 34, a decomposed granite and clay soil from Riverside, Calif.
Flume 54, a heavy clay soil from Riverside, Calif.
Flume 74, a sand and gravel wash from Uplands, Calif.
Flume 94, lava soil from central Idaho.
Flume 204, a sandy soil from central Idaho.

Figure 14 shows the rate of movement of soil moisture in these open flumes during periods of 20 to 55 days. Figures in circles indicate points at which that number of liters of water had been taken up.

Reviewing the results of these various experiments, the following features seem to call for special mention:

1. In all cases the water removed from the tank was lifted by capillarity a minimum vertical distance of 4 inches and then moved through soil in several directions.

2. The movement of soil moisture by capillarity is influenced by the type of soil, and such soil ingredients as soluble mineral salts, organic matter and colloids as well as by meteorological conditions.

3. When the source is a body of free water or saturated soil, water is moved by capillarity to heights of 15 to 60 inches or more during a single growing season, depending on the soil and other factors.

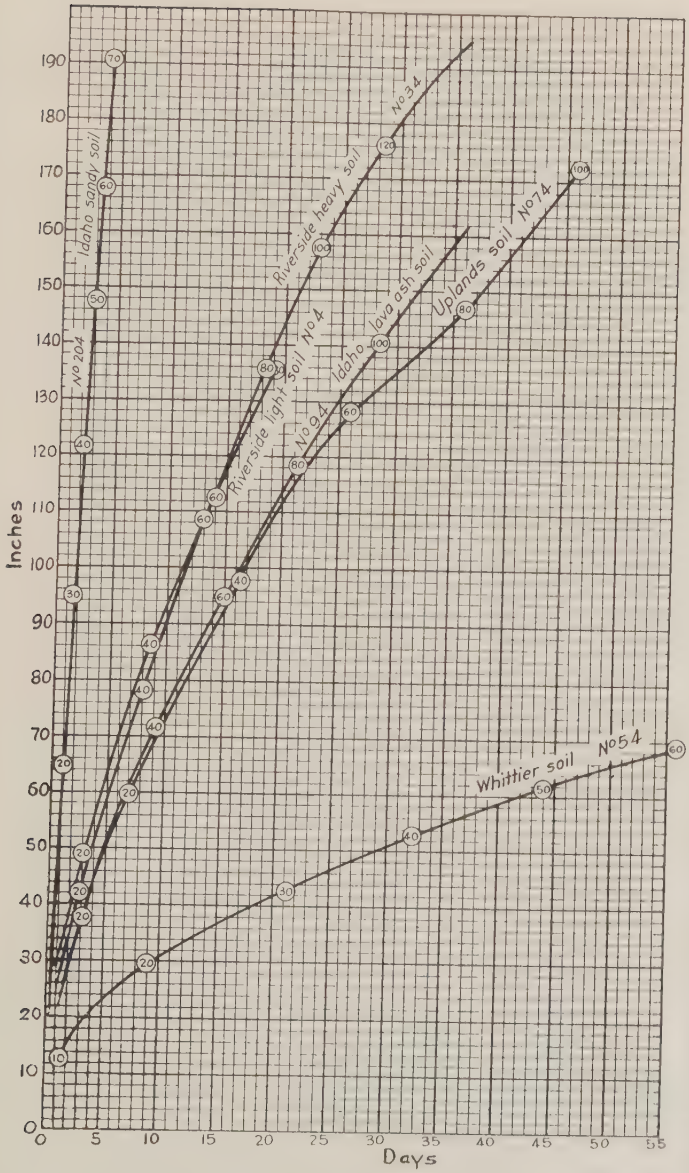


FIG. 14.—Rate of movement of moisture in open flumes inclined downward at 30 degrees from the horizontal. Figures in circles indicate points at which the numbers of liters of water have been taken up.

4. Due to the influence of gravity, the quantity of water and the distance through which it is moved by capillarity vary from a minimum in a vertically upward position to a maximum in a vertically downward position.

5. The capillary syphon, acting on an irrigation canal, and under favorable conditions, is capable of removing a relatively large volume of water in a period of 30 days, and distributing it by gravity and capillarity over a considerable distance.

6. In the design of a drain to remove the waste water from a given area of water-logged land, if L represents the volume of water that will drain from the area and stratum of saturated soil, and M the volume of water raised by capillarity above the water table, then the water to be removed is L-M, and the drain should be designed accordingly.

In McLaughlin's second group of experiments the source of water supply is moist soil. In other words, the capillary movement of moisture took place from a wet to an air-dry soil. The equipment used consisted of soil boxes placed in vertical and horizontal positions. The wet soil was placed, in some cases, at the top end of the box, in others at the bottom, and in others the wet soil was placed in the middle section and dry soils at both ends. Nearly all boxes were 6 feet in length, and the wet soil occupied one-half this length and the dry soil the other half. The following is a brief summary of the more important results:

1. The movement of soil moisture by capillarity is much slower and of smaller volume in the absence of free water.

2. Capillarity is much more active during the first few days than it is later when a dry soil is placed alongside a wet soil, or when dry soil is irrigated. Thus the movement of moisture up into a dry soil was about one-fourth as great in 4 days as it was in 56 days.

3. The rate and extent of the movement of moisture by capillarity decreases as the initial moisture content of the wet soil decreases.

4. Capillarity and gravity acting together tend to move water downward over greater distances and in about double the quantity than capillarity acting against gravity can move it upward.

5. The capillary movement of soil moisture in a horizontal direction as determined in horizontal boxes is greater in extent

than the upward movement in the vertical boxes, but not so great as the downward movement.

6. The amount of water moved upward by capillarity and the rate of movement from moist soil is not alone sufficient to maintain plants in a vigorous condition.

7. The tendency of plants when beginning to suffer from a shortage of water is to extend their roots to moist soil.

RATE OF FLOW OF SEEPAGE WATER.—The rate of flow of seepage and undergound waters generally depends upon a number of conditions. The chief of these are (1) the available head or gradient, (2) the relative porosity of the soil and (3) the temperature of the soil and water. In the following table, compiled from Water Supply Papers 67 and 140, U. S. Geological Survey, by Prof. Chas. S. Slichter, the velocity of flow is based on a fall or grade of 100 feet per mile, a porosity of 32 per cent and a temperature of 50°F.

TABLE NO. 14

Kind of soil	Diameter of soil grains, millimeters	Velocity	
		In feet per day	In miles per year
Silt	0.01	0.0038	0.00026
	0.04	0.0590	0.00408
Very fine sand	0.05	0.0923	0.00638
	0.07	0.1808	0.01250
	0.09	0.2989	0.02066
Fine sand	0.10	0.3690	0.02551
	0.15	0.8322	0.05753
	0.20	1.476	0.1021
Medium sand	0.25	2.305	0.1594
	0.35	4.520	0.3125
	0.45	7.471	0.5165
Coarse sand	0.50	9.224	0.6377
	0.65	15.57	1.077
	0.80	23.62	1.633
	0.95	33.30	2.302
Fine gravel	1.00	36.90	2.551
	3.00	332.1	22.96
	5.00	1067.0	63.77

CHAPTER III

THE NECESSARY EQUIPMENT AND STRUCTURES

11. Equipment for the New Settler.—Many advertisements for the sale of irrigated land state or leave the impression that men with but little capital and experience can easily make a success upon such lands. While it is true that the ability to do hard work, a willingness to suffer privations and a determination to succeed greatly supplement a small bank account, yet there are many demands for capital which must be met. Before purchasing, the prospective settler should either have sufficient money to meet such demands or know from whence he may secure it when needed.

The first expenditure required of the prospective settler is the first payment upon the land. This varies in price according to locality and the cost of developing the project. Prior to moving to the land a house should be built for habitation. The settler may provide a temporary structure but this should be fairly well built, since it may have to do service for several years. The size and cost of such a house and its furnishings will depend to a large extent upon the size of the family. In addition, a barn will be required for whatever live stock is purchased. The settler should provide himself with a good team and wagon complete with harness, an extra horse, a milch cow, two pigs and fowls.

For reclaiming, leveling and putting the land under cultivation, a plow, harrow, leveler and other implements will be required. While not absolutely necessary the settler will find that the purchase of a few miscellaneous tools for working in wood and metal will prove a great convenience. Some implements, such as a mower and hay rake, can, no doubt, be rented from some neighbor whenever needed.

Fencing the entire place may be out of the question for the first year or two, but should be done as soon as practicable in order to furnish pasturage for the cow, thus reducing the feed

bill to some extent. At any rate enough fencing should be provided to build a feed corral at the barn.

The settler should move to the farm some time during the fall or early spring, preferably the latter, before the cropping season begins in order to clear, plow and level a portion of the land for cultivation. This tilling of the soil will involve the purchase of seed and the yields for the first year will barely pay expenses of cropping and in many cases barely furnish enough seed for the increased acreage the following season. As the returns from the first season will be light, the settler must provide provisions for himself and family and feed for the livestock during the first season and the greater portion of the following season.

It is very doubtful whether the return from the crops will furnish a living to the settler and meet the expenses incurred by such improvements as will be required from time to time within several years. Usually, on most projects, the second payment with deferred interest falls due at the end of the first season and this money must be derived from outside sources.

At some certain date during the year, fixed by statute, the settler becomes subject to taxation for both personal property and real estate. Lands located upon Carey Act projects become taxable as soon as final proof is made, while those located upon Reclamation projects of the United States are not taxed until title is obtained. Assessments to provide for maintenance and operation charges for irrigation works must, of course, be met each year whether the land is patented or not.

No title to the land can be acquired until all payments have been made. As only equity to the land can be given as security for loans, interest becomes high and credit limited, making loans on real estate held in equity hard to float. Thus, payments with deferred interest cannot be raised by making loans on the place but must be derived from outside sources until such time as the farm has reached a paying basis.

The foregoing deals with the necessary financial outlays of the settler during the first few years of occupancy and the bare necessities in the way of equipment. Even this humble start on a 40-acre farm may require from $2,000 to $3,500 of capital or credit. To those who possess more means, better and more permanent equipment can be provided. This refers to a dwelling

and outbuildings, domestic water supply, a proper irrigation layout for the farm, farm ditches, thorough land preparation, fences, roads and structures. Some of these will be dealt with in subsequent articles.

A convenient farm dwelling of the better type and adapted to the colder parts of the West is shown in plan in Fig. 15.[1] Owing to the fact that few farm homes are provided with running water

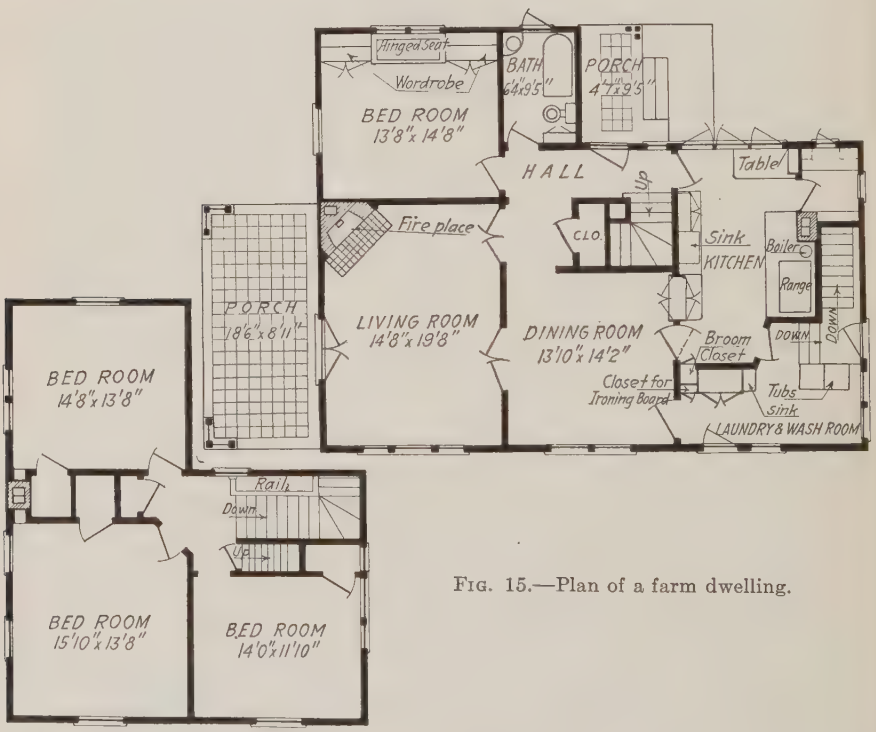


FIG. 15.—Plan of a farm dwelling.

in the second story, the bathroom is on the first floor but convenient to the stairs leading to the bedrooms on the second floor.

In these days of high living costs, the city dweller can effect a considerable saving by buying fruits and vegetables in shipping units such as a box or barrel of apples or a sack of potatoes, providing he has a suitable place to store them. Farmers must do

[1] A slightly modified plan of a farm house shown in *Farmer's Bull.* 1132.

more than this. Over the greater part of the West, the growing season is less than 6 months and rural populations are obliged to store vegetables and fruits for the remaining half year. Occasionally, properly ventilated and frost-proof root houses are provided for this purpose, but more often vegetables and fruit are stored in the cellar beneath the living rooms of the farm dwelling. Such a practice is bad for the health of the occupants, and tends to rot the stored products. An extension cellar connected with the cellar proper by double doors and extending beneath a shed attached to the dwelling costs little and pays well. The small space between the doors is used to store preserved fruit and the balance of the space is occupied by bins for vegetables and fruit. The cellar is well ventilated and drained and has an outside door which is used only in frost-free periods. The roof may be of arched concrete, but cedar logs serve the purpose well and are cheaper. Regardless of the material used for the roof there should be a layer of dry leaves and turf to insure protection from frost.

12. Farm Irrigation Layouts.—The most essential features in laying out an irrigation farm are good drainage and sanitation for the farmstead, properly located farm ditches, subdivision into fields and the adoption of right methods of land preparation and irrigation for each so that all parts may be readily and uniformly watered. As regards the location of the dwelling a number of questions should be considered, such as proximity to a public highway, wind exposure, outlook and accessibility to other parts of the farm; but since the health of the occupants is paramount, it is best to give drainage and sanitation a first place. Sometimes a part of the farm is too high to be watered by a gravity ditch and this cheap and dry part may be utilized for farm buildings and yards. This proves a good selection providing water can be pumped or otherwise secured for domestic, lawn and garden purposes. Farm houses should be set back at least 100 feet from roads or bare ground to avoid the discomfort of drifting dust and to assure an attractive setting of lawn and shrubbery. Whatever the source of the domestic water supply, whether from a well, cistern or spring, it should be carefully guarded from contamination. A water-tight cesspool or septic tank should be provided but if this can not be built great care

should be used to protect sewage from flies and to convey it beyond the possible reach of the water supply through surface channels or underground percolation. This highly important feature is commonly overlooked as may be seen in the careless location of sewage drains and outbuildings. Its careful observance is an excellent preventive of typhoid and similar disease. The homestead should likewise be protected from prevailing winds by a grove of trees of the variety best suited to the climate and soil. Poplar or cottonwood, and in localities of little frost, eucalyptus, when well watered, will grow rapidly. These may alternate with the slow-growing elms, box elders, oaks and peppers. Good roads and lanes lined with shade trees not only enhance the value of the farmstead, but add greatly to its attractiveness. The farm home and its surroundings in an irrigated district need not be expensive in order to be beautiful. Where there is an abundance of rich soil, a ready supply of water and a favorable climate, it is easy to convert a dreary abode into an attractive residence. Green grass soon covers the drifting sands, a climbing rose or a vine conceals an ugly exterior and the foliage of shrubs and trees affords shelter from the rays of the western sun.

Since the location and cost of permanent farm ditches depend to a large degree on surface configuration, it is a saving of money in the end to have a survey and topographic map made of the entire tract. If this cannot be done surface levels should be taken to fix the proper location of the fields, ditches and other permanent features. The supply ditch from the main canal or from one of its branches should be as short and as large as possible. The main points to be kept in mind in fixing its location are to convey the water with the least loss to the highest part of the farm, if practicable; to run parallel to fence lines or field borders; to avoid use of syphons, flumes or dikes; and to adopt a suitable grade. The capacity of the supply ditch, as well as the capacity and direction of the farm ditches, depends on the size of the farm and fields, the method to be followed in irrigating, the kind of crops which are likely to be raised and other considerations.

In laying out fields and permanent farm ditches, one should not overlook crop rotation. The same field may be in root crops one season, in cereals the next and in a legume the third. With

the exception of fruits, vines and a few other crops, rotation of one kind or another is quite generally practised under irrigation and it is well to plan farms at the start so as to conform to this use. Owing to the wide variation of soils on some farms and to the further fact that particular soils are adapted to particular crops, it is well to set aside a certain field for a special crop, such as fruit trees. The Director of the state experiment station of the state in which the farm is located may be with profit consulted on matters pertaining to soils, crops and climate.

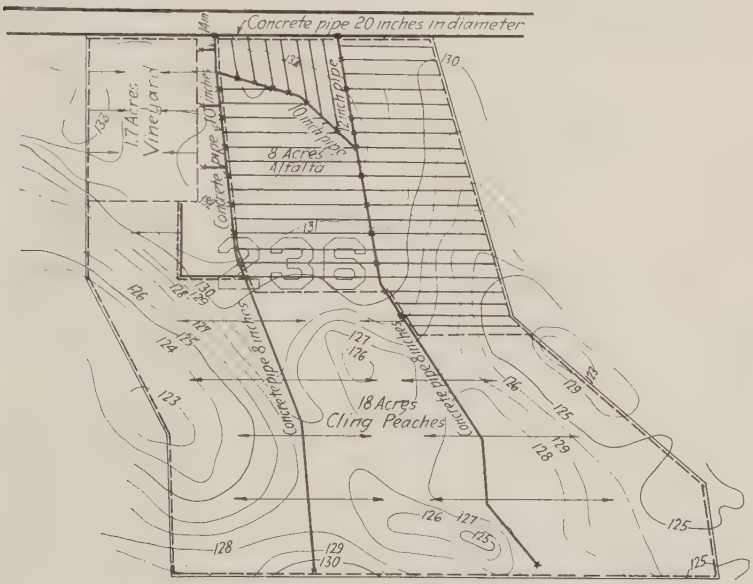


FIG. 16.—Irrigation layout of a farm at Delhi, Calif., where concrete pipe is used.

Western lands were surveyed without regard to irrigation requirements and it is only on smooth plains having flat slopes that the original land boundaries conform to the needs of irrigation. In recent years, the more experienced irrigation engineers in subdividing large holdings have considered topographic features rather than old survey lines and have laid out farms of the proper size that can be readily and cheaply irrigated. Such a farm, with an outline of its irrigation layout, is shown in Fig. 16. In the locality of this farm, which is located at Delhi,

Calif., the land is undulating and the soil sandy, and in order to conserve the water supply and facilitate its distribution over the land surface, concrete pipes were used instead of open ditches for the entire tract of 9,000 acres. The farm in question containing 28.7 acres is laid out in such a way that the eastern and western boundaries extend through the lowest land and the waste ditches follow these boundaries. The 20-inch concrete main which is laid along a highway parallel to the north boundary is tapped near the highest point and two distributary concrete pipe lines varying in diameter from 14 to 8 inches extend in a southerly direction and divide the farm into three nearly equal belts. Irrigation hydrants are placed at regular inters vals on these two pipe line- and from these water is furnished to border strips and furrows in the manner indicated. Up to date (1925) no buildings have been erected on this new farm.

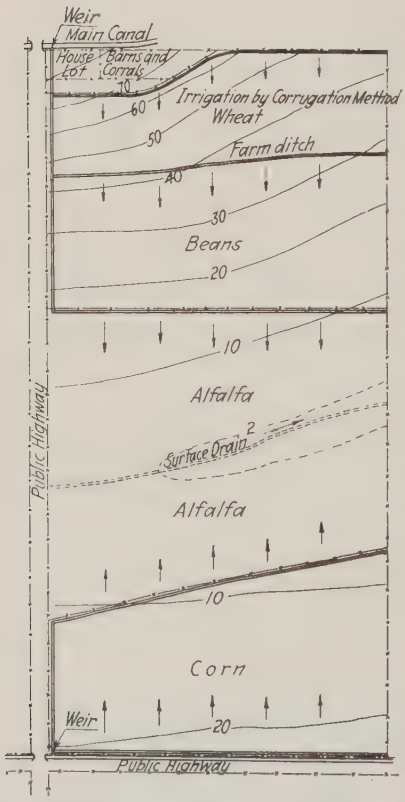


FIG. 17.—Typical 80-acre ranch in Idaho, showing outline of irrigation system.

An irrigation layout for an 80-acre diversified farm in southern Idaho is sketched in Fig. 17. The contours show that the farmstead is located at the highest corner and near the main canal and that there is a ravine extending across the lower half of the farm beyond which the land is irigated from a second supply ditch. This second supply ditch might have been dispensed with by building a flume or laying a pipe syphon along the edge of a portion of the west boundary. This farm is irrigated by the

corrugation method described elsewhere, and may be regarded as typical of southern Idaho.

Another irrigation layout typical of the Arkansas valley of Colorado is outlined in Fig. 18. This diversified farm of 160 acres, inclusive of highways, is divided into a number of fields

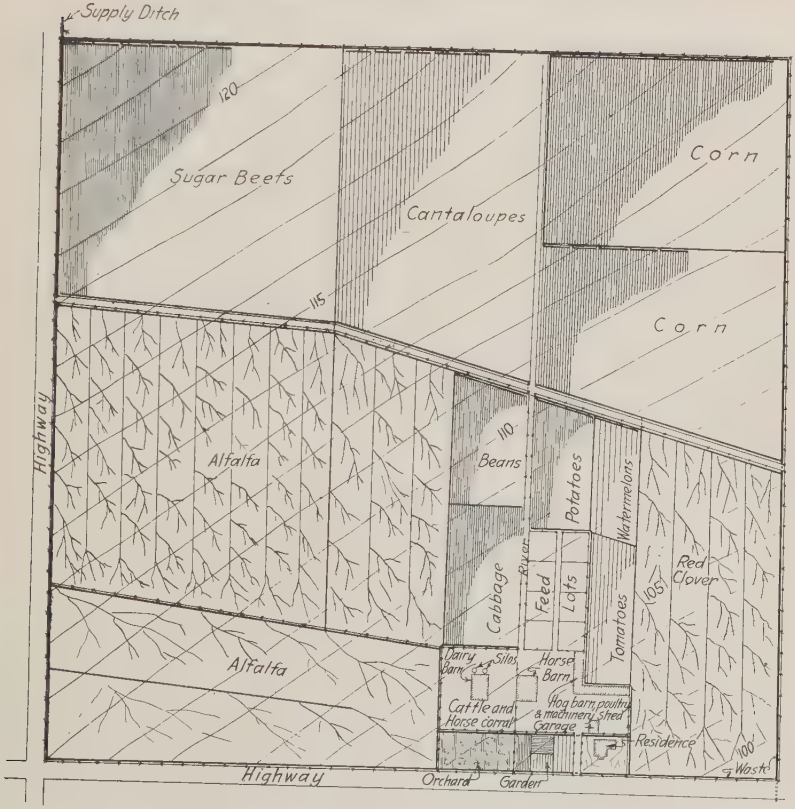


FIG. 18.—Farm irrigation layout in Arkansas Valley, Colorado.

each of which is irrigated by permanent head ditches. Two methods of irrigation are practised. The fodder crops are watered by flooding from field laterals and the balance of the crops by running water in furrows.

13. Farm Ditches.—Farm ditches are either permanent or temporary. The former include the main supply ditch to the farm and its various branches to subdivisions of the farm. The

latter are confined to the small distributaries in each field and are renewed for each crop.

Location.—The chief features to be considered in locating permanent farm ditches were pointed out in Art. 12. It may be stated here by way of emphasis that too much care cannot well be given to this subject since faults of location in such channels affect the whole farm. The most common mistake made by farmers is to lay out and build a system of ditches for a part of the farm without regard to the irrigation of the remainder. Since these are considered temporary in character little attention is paid to them, but after the lapse of years it is found both difficult and costly to abandon the old and begin anew.

Grade of Ditches.—The quantity of water which a ditch will carry depends fully as much on the fall or grade as on its size. The two elements should be considered together. When conditions are such that one can adopt a suitable grade the chief points to consider are the volume to be carried and the nature of the soil. The smaller the volume the greater the grade required. In a small ditch capable of carrying 50 miner's inches a fall of 2 inches to the rod would produce a velocity of 2 feet per second, while in a ditch capable of carrying 950 miner's inches the fall required to give the same velocity is only 1/4 inch to the rod. In fine sand or sediment a flat grade is required to prevent scouring. A mean velocity of 1 foot per second is sufficient for such material. In hard gravel or hard clay or in a mixture of these a velocity of 3 feet per second can be used without eroding the bottom. In ordinary materials, ranging from sandy or gravelly loams to clay loams, a grade may safely be adopted which will produce a mean velocity of 2 to 2 1/2 feet per second. On a farm with little fall the grade cannot exceed that of the land. On rolling land or where the slope is steep a suitable grade for ditches can usually be found by running them across the slopes rather than directly down them. When excessive grades can not be avoided by winding around the high places the speed of the water may be checked at intervals by the insertion of drops or a rough pavement of cobble stones loosely laid. Check boards are convenient to direct water into laterals, and at a slight additional expense they may be combined with a permanent drop. Considering the ditch alone it is preferable to use a grade which for its

size will give a velocity just safely less than will cause cutting in the type of soil through which it is to be built.

The grades to apply to produce the proper velocities in ditches and canals can only be determined by experience. The term "permissible canal velocity" may be taken to mean the highest mean velocity that will not scour beds or banks and at the same time will prevent as far as possible the deposition of silt and the growth of aquatic plants. In studying this question the author and his associate, F. C. Scobey, found that the presence of fine earthy material known as colloids in the channel or water, or in both, exerted a marked influence. The report of this subcommittee of the Committee on Irrigation Hydraulics of the American Society of Civil Engineers appears in the Transactions of the Society for 1925, but some idea of their conclusions on permissible canal velocities may be gained by the figures given in Table No. 15 which summarizes their findings.

TABLE NO. 15

Original material excavated for canal	Velocity after aging of canals carrying:		
	Clear water, no detritus, feet per second	Water bearing colloidal silts, feet per second	Water bearing non-colloidal silts, sands, gravels or rock fragments, feet per second
Fine sand (non-colloidal)	1.50	2.50	1.50
Sandy loam (non-colloidal)	1.75	2.50	2.00
Fine loam (non-colloidal)	2.00	3.00	2.00
Alluvial silts when non-colloidal	2.00	3.50	2.00
Ordinary firm loam	2.50	3.50	2.25
Volcanic ash	2.50	3.50	2.00
Fine gravel	2.50	5.00	3.75
Stiff clay (very colloidal)	3.75	5.00	3.00
Graded, loam to cobbles, when non-colloidal	3.75	5.00	5.00
Alluvial silts when colloidal	3.75	5.00	3.00
Graded, silt to cobbles, when colloidal	4.00	5.50	5.00
Coarse gravel (non-colloidal)	4.00	6.00	6.50
Cobbles and shingles	5.00	5.50	6.50
Shales and hardpans	6.00	6.00	5.00

Form of Ditches.—The principal function of both the permanent and the temporary ditches is to get water on the land quickly and easily. To do this the form of the ditch should be such that the water surface in the ditch is kept above the ground to be covered. Ditches should not be allowed to cut deeply into the ground so that diversion is hindered. When being built they

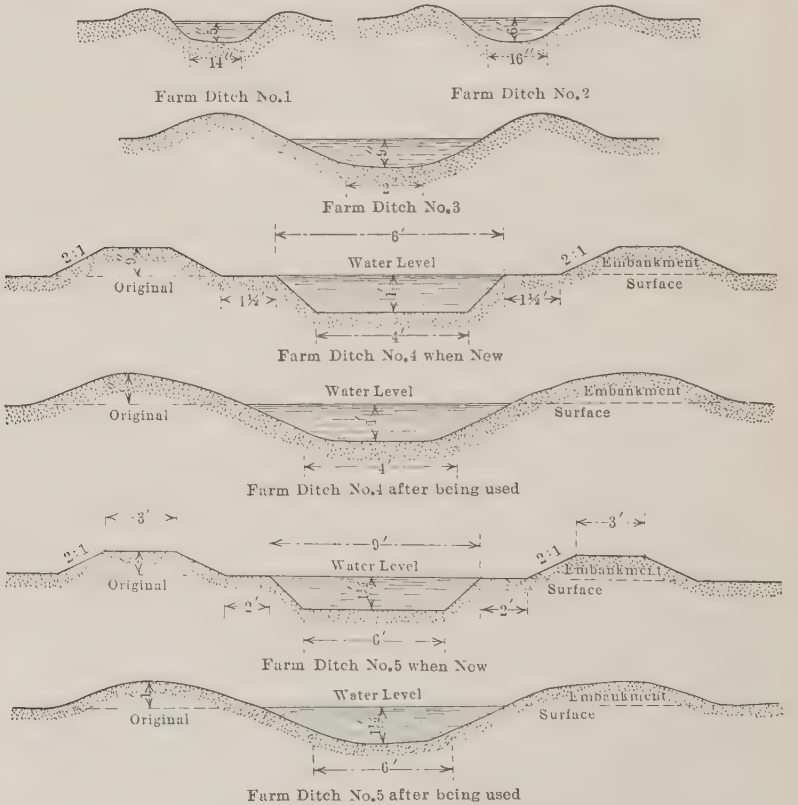


Fig. 19.—Farm ditches of various capacities.

should be well banked so that the turnouts can be made without having to raise the water above safe limits on the banks above. The form of the cross-section of a ditch depends largely on its method of construction. Small ditches made with a V-crowder are generally triangular in shape when built. If the velocity is

not such that scour will occur these usually become rounded as shown in ditches 4 and 5 (Fig. 19).

The larger ditches are usually constructed with a scraper working across from side to side making a bank on both sides in nearly level ground and on only the lower side in side-hill work. Such ditches are best built with curved cross-section as the squaring to a regular trapezoidal shape does not give advantages in proportion to the work required. In ditches made wide enough for a slip or scraper to be run along in the direction of the length of the ditch, the trapezoidal shape is as easily built as the curved. Typical shapes and dimensions for small ditches are shown in the accompanying cuts, the ditches shown being those for which the tables of capacity given later are computed.

Capacity.—The capacity needed depends chiefly on the manner of delivering the water and the methods used in applying it. It also depends, but to a less extent, on the size of the farm, the duty of water, the nature of the soil and the crops raised.

Flow of Water in Farm Ditches.—In the table which follows (Table No. 16) the flow in each of the five types of farm ditches previously shown (Fig. 19) has been figured for different grades. These grades are intended to cover ordinary conditions on most farms and are expressed in three ways: first, in inches and fractions of an inch per rod; next, in feet per 100 feet; and, lastly, in feet per mile. The mean or average velocity of the water in each kind of ditch having a given grade is also given, as well as the discharge in cubic feet per second and its equivalent in miner's inches under a 6-inch pressure head, about 40 of such inches being equal to 1 cubic foot per second. Thus, in farm ditch 3 a grade of 1/2 inch per rod produces a discharge of 168 miner's inches, but when the grade is increased to 3/4 inch per rod the discharge is 207 miner's inches.

Instruments Needed in Laying Out Ditches.—In laying out supply ditches an engineer's level and rod are the most convenient instruments. The distances may be estimated by pacing. When such instruments are not available, a useful substitute consists of an ordinary carpenter's spirit level attached to a portable wooden frame. When first made and placed on a level surface the bubble should come to the center of its run. Then one leg is shortened by the amount of the grade per rod (see

TABLE NO. 16.—TABLE GIVING THE MEAN VELOCITY AND DISCHARGE OF DITCHES WITH DIFFERENT GRADES

Grade			Mean velocity in feet per second	Discharge	
Inches per rod	Feet per 100 feet	Feet per mile		Cubic feet per second	Miner's inches under 6-inch pressure head
Lateral ditch with bottom width of 14 inches (ditch 1)					
1/2	0.25	13.33	1.01	0.67	27
3/4	0.38	20.00	1.23	0.81	32
1	0.51	26.67	1.42	0.93	37
1 1/4	0.63	33.33	1.59	1.05	42
1 1/2	0.76	40.00	1.75	1.16	46
2	1.01	53.33	2.04	1.35	54
2 1/2	1.26	66.67	2.28	1.50	60
3	1.51	80.00	2.50	1.64	66
3 1/2	1.77	93.33	2.70	1.78	71
Lateral ditch with bottom width of 16 inches (ditch 2)					
1/4	0.13	6.67	0.82	0.80	30
1/2	0.25	13.33	1.16	1.00	42
3/4	0.38	20.00	1.42	1.30	52
1	0.51	26.67	1.64	1.50	60
1 1/4	0.63	33.33	1.84	1.70	67
1 1/2	0.76	40.00	2.02	1.80	74
1 3/4	0.88	46.67	2.18	2.00	80
2	1.01	53.33	2.34	2.10	86
2 1/2	1.26	66.67	2.61	2.40	96
Lateral ditch with bottom width of 2 feet (ditch 3)					
1/8	0.06	3.33	0.79	2.08	83
1/4	0.13	6.67	1.13	3.00	119
1/2	0.25	13.33	1.60	4.20	168
3/4	0.38	20.00	1.97	5.20	207
1	0.51	26.67	2.28	6.00	239
1 1/4	0.63	33.33	2.57	6.80	270
Lateral ditch with bottom width of 4 feet (ditch 4)					
1/16	0.03	1.58	0.84	4.20	168
1/8	0.06	3.33	1.08	5.40	216
1/4	0.13	6.67	1.54	7.70	308
3/8	0.19	10.00	1.89	9.50	378
1/2	0.25	13.33	2.20	11.00	440
5/8	0.31	16.67	2.45	12.20	490
3/4	0.38	20.00	2.69	13.40	538
Lateral ditch with bottom width of 6 feet (ditch 5)					
1/16	0.03	1.67	1.03	11.6	464
1/8	0.06	3.33	1.48	16.7	666
3/16	0.09	5.00	1.82	20.5	819
1/4	0.13	6.67	2.11	23.7	950
5/16	0.16	8.33	2.35	26.4	1,058
3/8	0.19	10.00	2.58	28.0	1,121
7/16	0.22	11.67	2.80	30.5	1,260

Table of Grades). The device is operated by one man, who first places the shorter leg at the surface of the water in the main canal or supply ditch and swings the other end around until the bubble comes to the center. The location of the longer leg is then marked by a helper, who carries a shovel and removes part of a shovelful of earth. The level is then carried forward until the shorter leg occupies the position vacated by its mate, when a second mark is made. This operation is repeated until the line is laid out and a furrow is run connecting all of the temporary marks.

CONSTRUCTION.—Usually for the construction of farm ditches the ground is plowed to the width desired. With small ditches a lister or ditch plow may be run through once and the ditch shaped by hand or with a small log crowder. With larger ditches as many furrows as needed can be plowed and a V-crowder used to shape the ditch and pile the earth in the banks. By varying the shape of the V or by the driver and helper shifting their weight in riding the crowder, the ditch can be shaped to almost any desired form. A wing plow can be used to plow and clean the ditch at the same time. For large ditches, graders can be used. A greater range of adjustment of the blade is needed for ditch work than for leveling.

In case it is necessary to build the ditch in fill over low places, the necessary dirt for the fill can be brought from the adjoining ground and the ditch shaped on its top as in level ground.

If possible ditches should be built some time before use so that the banks may have time to settle. In case the banks are still soft when water is first run great care should be taken to avoid breaks.

MAINTENANCE.—Maintenance of farm ditches aside from the repairs to structure is principally of two kinds, the prevention or removal of weeds and the cleaning out of silt and aquatic growths. In the case of weeds, prevention where practicable is preferable. Irrigation waters usually carry weed seeds. If the grade of the farm ditch is such as to give as high a velocity as in the lateral from which the water is received, the weed seed and silt can be largely carried on through to the fields. More trouble is generally experienced from weeds on ditches with low velocities. The planting of alfalfa or other crops on the ditch banks is a

preventive measure. The cutting of weeds before they seed at slack times is another. In some cases aquatic growths occur which reduce the carrying capacity to such a degree that irrigation must be stopped and the ditch cleaned. These growths may be grass growing in the water or on the banks and dropping over into the ditch or they may be trailing moss, water cress, or other forms of water plants. In ditches in use only a part of the time, the moss is usually killed during the periods the ditch is dry. The grasses, however, grow best at such times in the wet mud of the ditch bottom. In farm ditches the grasses can be mowed with a hand scythe without having to shut off the water. Regular and smooth banks will allow the use of the mowing machine for a large part of the weeds and grass leaving only the finishing for the scythe. The cleaning of ditches is generally a necessity in the spring whether the ditch is one that scours or one that silts. In a ditch which scours, the undercut banks will need shaping. In a ditch which silts, the deposits will need to be removed. This may be done either by hand shoveling where small in amount or by any of the methods described for the original construction.

14. Irrigation Structures for the Farm.—The structures which may be used on an irrigated farm in connection with the use of water include headgates, measuring devices, flumes, pipes, culverts, wells, cisterns, reservoirs, etc. Many of these have been described under other headings and need not be considered here.

Delivery Gates.—A headgate is needed to control the flow from the main or branch canal into a private ditch. The gate and its framework, together with the pipe or box which conducts the water out of the canal into the farmer's ditch, is sometimes termed a turnout. A structure of this kind should meet the requirements of both the canal company and the water user. The interests of the water company demand that it be secure, water-tight when closed, large enough to admit the necessary flow and so designed that it will not discharge after adjustment more than a certain fixed quantity of water. The water user is likewise interested in having a substantial structure of ample size, but in addition he desires it to be designed in such a way that he can, when he chooses, close it partly or altogether.

A wooden headgate with screw lift designed by J. L. Rhead and used by the writer on the Bear River Canal laterals is shown in Fig. 20.

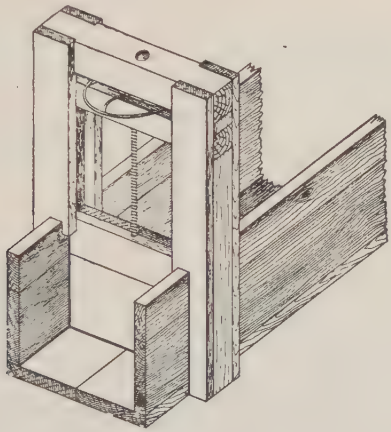


FIG. 20.—A wooden head gate with screw lift and lock.

A somewhat similar type made of creosoted wood which has been in use on the Medina Canal system of Texas for the past 10 years is shown in Fig. 21.

FIG. 21.—Creosoted wood sublateral headgate installed on Medina Canal, Texas. In service more than ten years, and still in good condition.

A more durable delivery gate made by the Concrete Machinery & Supply Co., of Los Angeles, Calif., consists of a metal gate and frame attached to a short line of pipe laid beneath the canal bank.

The pipe may be vitrified clay, concrete or steel. Figure 22 shows a connection made with a steel pipe.

A combination wooden and concrete check used on the Rio Grande reclamation project in New Mexico is shown in Fig. 23.

One of the latest types of gates in use in the Imperial Valley, California, for admitting water to borders is made by molding a

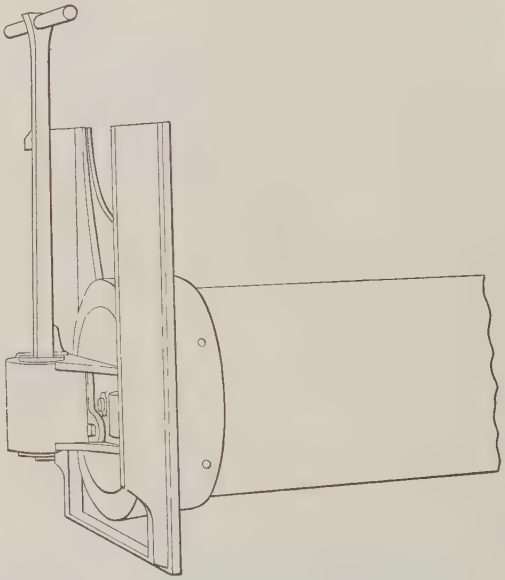


FIG. 22.—Metal delivery gate and frame.

concrete head on a joint of concrete pipe, the opening being regulated by a galvanized-iron gate held in place by springs. The gate is manipulated by an iron handle or wooden frame fastened to the gate. Figure 24 shows the essential features of this design.

A concrete gate with wooden flashboards used near Turlock, Calif. is shown in Fig. 25.

The chief points to be considered in the installation of such structures are: (1) To secure an advantageous location in tapping the canal so that water can be readily conveyed from it to the highest point of the farm to be irrigated; (2) to take the neces-

sary precautions to render the structure secure by cut-off walls and earth puddling and packing; and (3) to place the gate on such a level that it will draw its full supply when the canal is only partly full.

Concrete is being used more generally in recent years for farm structures of various kinds. It is particularly well adapted to the irrigated farm where it is used to control, measure and distribute water. It is also the best material for cellar walls, foundations, cisterns, well linings, culverts and the like. The mixture for such purposes should contain more cement and less gravel or

FIG. 23.—Check gate used on Rio Grande project, New Mexico.

broken rock than is commonly used for the larger engineering works. The author has used for farm structures a mixture of one part by volume of cement, two parts of sand and four parts of gravel or broken rock with some rock dust. In mixing small batches two buckets of sand are first placed on a wooden platform and one bucket of cement added. The two are mixed with a hoe until they are of one color. Sufficient water is then added to make a fairly thin mortar, when the gravel or rock which has been previously wet and drained is dumped on the mortar. The mass is then turned over with shovels about three

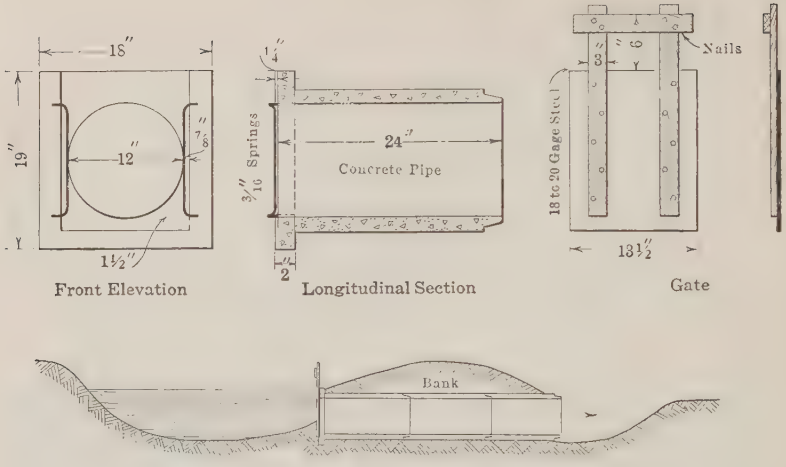


FIG. 24.—Gate in use in Imperial Valley, California.

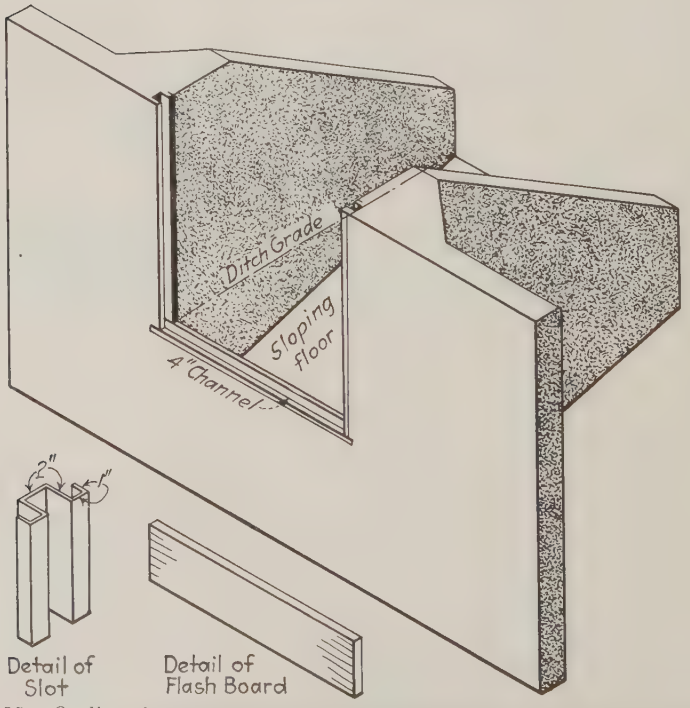


FIG. 25.—Outline of concrete gate and wooden flashboard as used on the Turlock Irrigation District, California.

times, transported to the place of use and well tamped in place. Forms for a cellar wall are shown in Fig. 26.[1]

Culverts.—Various devices are used to conduct the flow of ditches across roads. A loose plank bridge or else a culvert

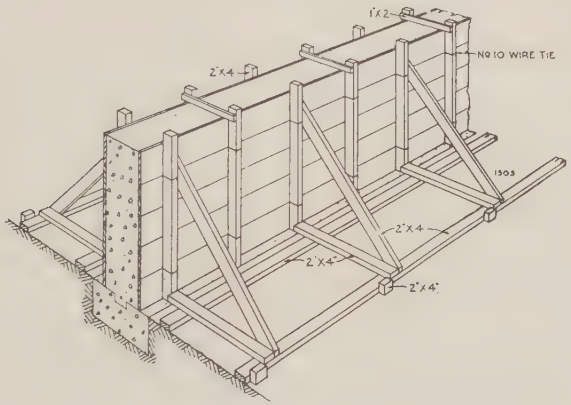


Fig. 26.—Straight wall form for level ground.

formed of four planks of the requisite size and length are both quite common. Unless lumber is cheap the short life of the former and the inconvenience of the latter render it worth while

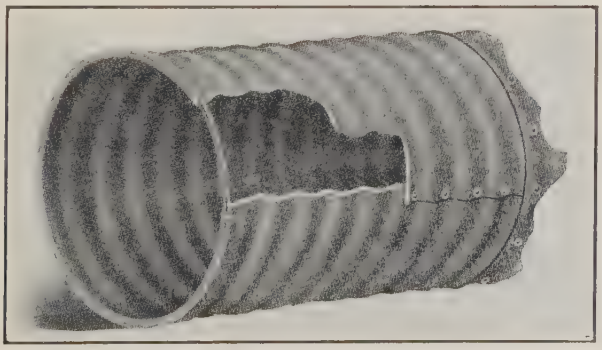


Fig. 27.—Corrugated pipe of ingot iron used for culverts.

adopting a more durable structure. Perhaps the best substitute for lumber is the metal pipe and one of the most durable and

[1] "Plain Concrete for Farm Use," *Farmer's Bull.* 1279.

easily installed pipes is the corrugated culvert pipe (Fig. 27) made of ingot iron. This is made in sizes ranging from 8 to 84 inches in diameter and two or more shipping lengths may be riveted together if necessary. In depressed crossings and wherever the pipe is under water pressure the seams of the pipe should be calked.

Water for Domestic Uses.—The settler under an irrigation enterprise has seldom an opportunity to obtain water from either springs or reservoirs for culinary and stock purposes. As a rule such supplies are obtained from the main canal or one of its distributaries or else from wells. Before canal water can be used for domestic purposes with safety to health it should be filtered. Filters are sometimes made by inserting a partition wall of porous brick within a cistern and allowing the canal water to filter through the wall. This practice is not to be recommended on account of the difficulty in cleaning or removing the filter which soon becomes foul and clogged. A better plan is to filter the water in a separate vessel and conduct it from the filter to the cistern where only pure water is stored. The filter may consist of a concrete box with coarse gravel in the bottom and a depth of 15 inches of sand on top. A large oak barrel is a good substitute for the concrete box. In using a barrel a false bottom is inserted 2 or 3 inches above the true bottom and pierced with a number of holes which are covered with a brass wire screen. The filter consists of a thin layer of gravel, about 15 inches of sand and the same depth of water. The filtered water is conducted through a small pipe from the bottom of the barrel direct to the cistern. When the cistern is filled the sand should either be discarded or else exposed to the sun and air until again used.

The concrete cistern shown in Fig. 28[1] may serve as a model with the exception of the partition wall which is of doubtful utility. In constructing a cistern of this kind, make a circular excavation 16 inches wider than the desired diameter of the cistern and about 16 inches deeper than the desired depth. Make a cylindrical form as shown in the figure, the outside diameter of which will be the inside diameter of the cistern. Mix the concrete in small batches fairly wet and tamp in between the

[1] *Bull. 57, U. S. Dept. of Agr.*

form and the earth. To construct the conical portion build a floor across the top of the cylindrical form, leaving a hole of the desired size in the center. Brace the floor well with uprights from the cistern bottom. Build a cone-shaped mould of wet earth or sand and lay the concrete and reinforcing on this cone. Allow it to set and harden well before removing the forms and earth.

A large number of different types of wells are used throughout the arid region to secure potable water. The most suitable type to select depends to a great extent on local conditions and the practice followed in the neighborhood affords the best guide.

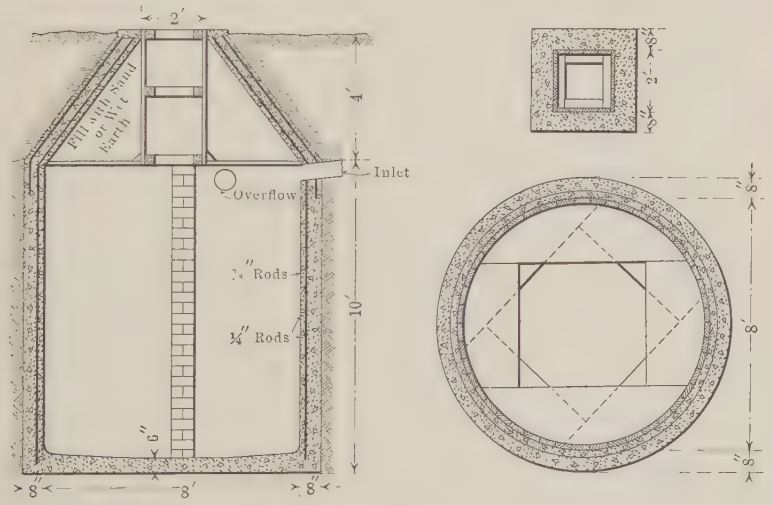


FIG. 28.—Concrete cistern for farm use.

One can usually secure the services of a contractor having the necessary equipment who will undertake to sink or bore a well at a certain price per foot.

The water required in farm houses varies with the appliances used, the character of the home, number of occupants and other features. If Monday is wash day and Saturday evening bath night much more than the average quantity of water will be required on these days.

The following may be taken as an approximate guide to the quantity of water required per day for the farm home and for each domestic animal.

	Gallons per Day
Family of five with bath	50 to 100
1 horse	7 to 10
1 steer	8 to 12
1 milk cow	10 to 16
1 pig	2 to 3
1 sheep	2 to 3

Where it is desirable to combine water supply for domestic purposes with that of irrigation for a garden, lawn, shade trees or small orchard the water may be pumped from a canal, well or other source by means of a windmill, gasoline engine or motor.

A standpipe, tank or reservoir is often a necessary part of small water supplies designed to serve a number of purposes. If the right elevation can be obtained a reinforced concrete standpipe forms an excellent part of a pumping plant since it can be designed in such a way as not only to store considerable water but to act as an equalizing and distributing reservoir.

In a flat country the pumped water is usually stored in an elevated tank. Concrete is too heavy for such a purpose but redwood stave pipe of large diameters may be substituted.

Where conditions are favorable, a reservoir should be substituted for the standpipe and tank on account of its cheapness, durability and larger capacity.

15. Pipes and Pipe Systems for the Farm.—The use of pipe for the carriage of water and of pipe systems for its distribution over fields and orchards not only prevents loss of water, but affords better facilities for its control, delivery and application. Irrigating crops by means of earthen ditches is a laborious and unpleasant task wasteful of water, time and effort. On the contrary, it can be rendered comparatively easy and pleasant if the proper equipment is provided in the way of pipe, and pipe systems with proper gates, hydrants and other fixtures.

The materials composing the pipes most commonly used by irrigators are concrete, clay, wood and metal. A brief description of each of these kinds follows:

Concrete Pipe.—The rise and progress of the concrete-pipe industry do not differ materially from those of many other new

[1] "The Use of Small Water Supplies for Irrigation," by the author, *Yearbook, U. S. Dept. Agr.*, 1907.

industries. It has been evolved from small beginnings in a relatively short time, and although the annual output is now large, over 1,200 miles of concrete pipe having been made in California in one year, little had been done prior to 1917 to ascertain the strength and other properties of concrete pipe made by different processes or to establish proper standards for the ingredients used and the manner of mixing and making a high quality of product. In 1917 the Division of Agricultural Engineering of the U. S. Department of Agriculture, in cooperation with the State Department of Public Works of the State of California and the California Associated Pipe Manufacturers, began an investigation with the object of bettering this industry. This work was carried on for a number of years and resulted in a marked improvement in most of the concrete pipe made in the state of California and throughout the Pacific states. Apparatus was developed to test individual lengths of pipe as well as a series of lengths in combination. Much time was devoted to making ring and pipe specimens of different materials and proportions in order to ascertain their properties when subjected to a breaking test. The effects produced by the following-named factors were also determined: Proportion of cement; use of a certain percentage of fine material such as limestone dust or clay; varying the consistency; heavy and light tamping; proportioning and grading the materials; quantity of water to use; method of manufacturing; reinforcing; and curing.

Table No. 17 is a sieve analysis of a mixture recommended for small concrete pipe.

TABLE NO.[1] 17.—SIEVE ANALYSIS OF MIXTURE RECOMMENDED FOR SMALL CONCRETE PIPE

NUMBER OF SIEVE	PERCENTAGE PASSING
200	3
100	5
50	10
30	23
20	37
10	50
1/4	77
1/2	100

[1] Tables No. 17 and 18 are reproduced from a report by E. C. Fortier, Chief Engineer of the Delhi State Land Settlement, Calif.

Somewhat typical proportions for concrete pipes 18 to 42 inches in diameter are given in Table No. 18.

Table No. 18.—Typical Proportions for Large Concrete Pipe

Diameters	18 to 24 inch, cubic feet	30 inch, cubic feet	36 inch, cubic feet	42 inch, cubic feet
Cement	1.00	1.00	1.00	1.00
Fine sand No. 20 screen down	0.36	0.00	0.00	0.00
Rock screenings 3/8 inch down	0.00	1.04	1.63	1.43
Coarse sand 1/4 inch down	1.14	1.52	1.00	1.00
Pea gravel 1/2 inch down	1.50	0.00	0.00	0.00
Crushed rock 3/4 inch down	0.00	1.52	1.63	1.43

In specifying for the strength of concrete pipe, samples picked for test should show a tensile strength in concrete of the shell of the pipe of at least 250 pounds per square inch for pipe 6 to 16 inches in diameter. Pipes 18 to 42 inches in diameter should show a tensile strength in the concrets of the shell of at least 200 pounds per square inch.

The size, price and weight of thin-shelled pipe applicable to general farm use and for heads up to 40 feet for sizes 8 to 14 inches in diameter, 30 feet for sizes 16 and 18 inches and 25 feet for sizes 20 and 24 inches as manufactured by the Merritt Concrete Products Company, of San Jose, Calif., are given in Table No. 19. This firm also manufactures a medium-wall-thickness pipe for heads 50 per cent higher than those given for thin-shelled pipe, and double-wall-thickness pipe for heads up to 125 feet for sizes up to 14 inches in diameter. In the following table the installed price includes pipe and laying but not earth work and hauling:

TABLE No. 19

Size of pipe, inches	Yard price	Installed price	Weight per foot, pounds
8	$0.25	$0.33	27.0
10	0.30	0.40	37.6
12	0.38	0.50	46.2
14	0.48	0.63	56.4
16	0.65	0.88	75.2
18	0.82	1.05	98.8
20	1.02	1.26	130.0
24	1.50	1.75	180.8
30	1.80	2.76	265.0
36	3.00	3.72	425.0

VITRIFIED CLAY PIPE.—Pipe made of molded clay, kiln-burned and glazed, is extensively used to conduct sewage in the sewer systems of towns and cities. The requirements for this service are quite rigid and the pipe which is rejected by the sewer inspector can frequently be purchased at a low figure. In this way the irrigator who resides within hauling distance of a town or city can usually obtain from the municipality or the clay-pipe com-

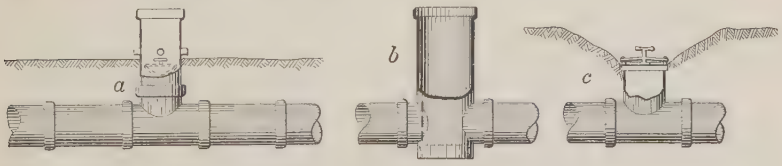


FIG. 29.—Fittings for vitrified clay pipe.

pany a serviceable water pipe for low heads at reasonable prices.

Manufacturers of clay pipe furnish standpipes and other fittings similar to those furnished by the concrete pipe makers. The stand shown in Fig. 29 is used for orchard irrigation. A special fitting is also made for the insertion of a gate on a pipe line and a T-joint with an "alfalfa" valve in position on the vertical branch as also shown.

The size, weight, dimensions and price of standard strength clay pipes, as made by the Gladdin McBean Company, of Lincoln, Calif., are given in Table No. 20. The prices given are

net (Jan. 1, 1925) and include freight to any point in California where the freight rate does not exceed $5 per ton.

TABLE No. 20

Inside diameter, inches	Weight per foot, pounds	Length, feet	Thickness, inches	Depth, socket, inches	Annular space, inches	Area, square inches	Price per foot
3	6	2	1/2	1 1/2	1/4	7	0.12
4	8	2	9/16	1 1/2	3/8	12 1/2	0.15
5	12	2	5/8	1 3/4	3/8	19 1/2	0.18
6	16	2	5/8	2	3/8	28 1/2	0.21
8	22	2 1/2	3/4	2 1/4	3/8	50 1/4	0.30
10	31	2 1/2	7/8	2 1/2	3/8	78 1/2	0.42
12	41	2 1/2	1	2 1/2	1/2	113	0.54
14	50	2 1/2	1	2 1/2	1/2	154	0.66
16	63	2 1/2	1 1/8	2 1/2	1/2	201	0.84
18	80	2 1/2	1 1/4	2 3/4	1/2	254	1.02
20	93	2 1/2	1 3/8	3	1/2	314	1.20
22	125	2 1/2	1 1/2	3	1/2	380	1.59
24	142	2 1/2	1 5/8	3 1/4	1/2	452	1.80
Double Strength Pipe							
15	65	2 1/2	1 1/4	2 1/2	1/2	177	0.90
18	100	2 1/2	1 1/2	3	1/2	254	1.26
21	128	2 1/2	1 3/4	3	1/2	346	1.68
24	165	2 1/2	2	3	1/2	452	2.16
27	225	2 1/2	2 1/4	3 1/4	3/4	573	3.00
30	265	2 1/2	2 1/2	3 1/2	3/4	707	3.60

RIVETED STEEL PIPE.—Riveted steel pipe with slip joints is made in sizes of 4 to 36 inches in diameter and of various gages of metal. The American Steel Pipe and Tank Company, of Los Angeles, Calif., uses long sheets to make slip-joint pipe, there being only one round seam in 20 feet of pipe. These 20-foot lengths are double dipped in hot asphalt and before laying are distributed along the trench with the large end of each toward the source of water supply and lapping about three inches. The pipe is laid in the trench on wooden blocks 2 inches thick. Before telescoping the joints, distillate is poured on the inside of the large end and lighted. It is allowed to burn until the coating is

soft when the joint is formed by the operation of a lever and two clamps which telescope the lengths of pipe to the required extent.

The price of slip-joint pipe, weight per foot and safe head as made by this firm, Jan. 1, 1925, are as given in Table No. 21.

TABLE No. 21

Diameter in inches	No. 16 gage			No. 14 gage			No. 12 gage		
	Price per foot	Weight per foot, pounds	Safe head, feet	Price per foot	Weight per foot, pounds	Safe head, feet	Price per foot	Weight per foot, pounds	Safe head, feet
4	$0.29	3.7	390	$0.34	4.4	480			
5	0.34	4.4	360	0.40	5.4	450			
6	0.41	5.3	340	0.49	6.4	490			
7	0.45	6.2	325	0.53	7.4	450			
8	0.50	7.0	315	0.59	8.4	394	$0.80	11.6	553
9	0.55	7.8	280	0.65	9.4	350	0.87	12.9	490
10	0.61	8.6	252	0.74	10.4	316	1.00	14.3	443
12	0.71	10.3	210	0.85	12.4	263	1.17	16.9	368
14	0.79	11.8	180	0.96	14.4	226	1.34	19.6	317
16	0.89	13.4	158	1.07	16.3	198	1.50	22.3	277
18	0.98	15.1	140	1.20	18.3	175	1.66	24.9	246
20	1.10	16.7	126	1.35	20.3	158	1.85	27.5	221
22	1.21	18.3	115	1.49	22.2	143	2.02	30.1	201
24	1.32	19.8	105	1.60	24.2	131	2.18	32.6	184
26	....	....	...	1.73	26.2	121	2.36	35.1	170
30	....	....	...	1.99	30.1	106	2.69	40.1	147
32	....	....	...	....	....	...	2.85	42.5	137
36	....	....	...	....	....	...	3.17	47.5	122

WOOD PIPE.—The various kinds of wood pipe used to convey water for irrigation purposes belong to one of two general types. One of these is the continuous stave pipe and the other the machine-banded pipe. Since the former is only built in medium and large sizes in which the diameters run from 1 to 13 1/2 feet, it is not well adapted to the farmer's needs and for that reason will not be considered here.

The factory for making machine-banded pipe in San Francisco, Calif., uses redwood; those located in Portland, Ore.; Tacoma and Seattle, Wash.; and Vancouver, B. C., use fir. In the states of New York and Pennsylvania the pipes are made of white pine and tamarack, while in Louisiana cypress is considered the most suitable wood.

The Continental Pipe Manufacturing Company, of Seattle, Wash., is the largest maker of wood pipe in the world and the methods used by this firm in making wire-wound pipe are briefly outlined. Only the highest grade of Douglas fir lumber grown on the Pacific slope of the continent is used. The staves are dressed on both sides and edges to true curves and bevels in accordance with the size and thickness of shell desired. The wire used is of mild steel, strong and elastic, and heavily galvanized. After the staves are milled and rigidly inspected they are set up in building forms and clamped into the shape of a pipe. This section of pipe is then placed in the banding machine and wrapped with wire under sufficient tension to embed the wire slightly into the wood. At the finishing end, a clip made of Norway iron, having prongs which penetrate the wood, is used. Three wraps of the wire pass through this clip, which is then hammered down solidly over the wires. The wire is then cut off and turned back over the top of the clamp and stapled.

After the pipe is banded, it is placed in position on the heading machines and the ends of the pipe are shaped to suit the joint or coupling desired.

The pipe goes from the heading machine to the dipping vat containing a mixture of hot tar and asphalt where it is dipped on the outer surface only and is then rolled down an incline covered with fine sawdust which adheres to the coating and is not easily abraded.

Several types of wire-wound pipe are made which differ chiefly in the kind of joint used and the water pressure to be withstood.

1. Wire-wound pipe with inserted joints is used for comparatively low heads except in the smaller sizes and the joint is made by reaming out one end of the pipe for a socket and forming a tennon on the other end.

2. Creosoted wooden collars wrapped in the same manner as the pipe are used to make the joints.

3. The reinforced inserted joint is made by strengthening the socket end by inserting one or two steel rods and coupling the ends of each in a manner similar to the steel bands of continuous stave pipe.

4. In the individual banded coupling there are creosoted wooden collars as in (2) but these are wound with individual bands instead of wire.

At a slightly increased cost (see table of prices) wood pipe is made of creosoted staves and this preservative process greatly prolongs their life under adverse conditions.

Under suitable temperatures and vacuum pressures, the moisture and wood sap are withdrawn and approximately 8 pounds of creosote per cubic foot of wood treated is injected. The chief objection to the use of untreated wood pipe is its liability to decay, and the creosoting process for the preservation of wood is so well and favorably known as to recommend it to the purchasers of wood pipe.

The Continental Pipe Manufacturing Company makes wood pipe in diameters up to 14 feet, but the size of the wire-wound pipe is limited to diameters of 2, 3, 4, 5 and 6 inches and the even numbers from 6 to 24 inches. The price per foot increases with each 50 feet of water pressure up to 400 feet. The following table is confined to heads of from 50 to 250 feet and the prices f.o.b. cars, Seattle, apply to Jan. 1, 1925.

TABLE 22

Diameter of pipe	Head	Kind of joint	Weight per 100 feet	Price per 100 feet, untreated and coated	Add per 100 feet for creosoted pipe	
					Uncoated	Coated
Inches	Feet		Pounds			
2	50	Inserted joint	327	$20.00	$3.00	$4.00
	100	Inserted joint	337	21.00	3.00	4.00
	250	Inserted joint	376	24.00	3.00	4.00
3	50	Inserted joint	426	25.00	4.00	5.00
	100	Inserted joint	440	26.00	4.00	5.00
	250	6-inch wire-wound collar	497	33.00	4.00	5.00
		Add to the above prices for collars instead of inserted joint, where specified, per 100 feet		$ 2.00		
4	50	Inserted joint	563	31.00	6.00	8.00
	100	Inserted joint	579	32.00	6.00	8.00
	250	6-inch wire-wound collar	646	40.00	6.00	8.00
5	50	Inserted joint	668	36.00	7.00	9.00
	100	Inserted joint	687	38.00	7.00	9.00
	250	6-inch wire-wound collar	774	48.00	7.00	9.00
		Add to the above prices for collars instead of inserted joint, where specified, per 100 feet		$ 3.00		

Above weights are approximate.

TABLE 22.—*Continued*

Diameter of pipe	Head	Kind of joint	Weight per 100 feet	Price per 100 feet, untreated and coated	Add per 100 feet for creosoted pipe	
					Uncoated	Coated
Inches	Feet		Pounds			
6	50	Inserted joint	852	44.00	8.00	10.00
	100	Inserted joint	870	46.00	8.00	10.00
	250	6-inch wire-wound collar	990	57.00	8.00	10.00
8	50	Inserted joint	1,081	55.00	10.00	13.00
	100	Inserted joint	1,119	58.00	10.00	13.00
	250	6-inch wire-wound collar	1,305	74.00	10.00	13.00
		Add to the above prices for collars instead of inserted joint, where specified, per 100 feet		$ 4.00		
10	50	Inserted joint	1,367	69.00	13.00	16.00
	100	Inserted joint	1,430	74.00	13.00	16.00
	250	6-inch wire-wound collar	1,675	95.00	13.00	16.00
		Add to the above prices for collars instead of inserted joint, where specified, per 100 feet		$ 5.00		
12	50	Inserted joint	1,680	79.00	16.00	20.00
	100	Inserted joint	1,769	85.00	16.00	20.00
	250	8-inch wire-wound collar	2,155	117.00	16.00	20.00
		Add to the above prices for collars instead of inserted joint, where specified, per 100 feet		$ 6.00		
14	50	Inserted joint	1,957	92.00	18.00	22.00
	100	Reinforced inserted joint	2,097	102.00	18.00	22.00
	250	8-inch wire-wound collar	2,692	145.00	18.00	22.00
		Add to the above prices for collars instead of inserted joint, where specified, per 100 feet		$ 7.00		
16	50	Reinforced inserted joint	2,404	$116.00	$21.00	$26.00
	100	Reinforced inserted joint	2,549	127.00	21.00	26.00
	250	8-inch individual banded collar	3,354	189.00	21.00	26.00
		Add to the above prices for collars instead of inserted joint, where specified, per 100 feet		$ 9.00		
18	50	Reinforced inserted joint	2,674	131.00	24.00	29.00
	100	Reinforced inserted joint	2,880	148.00	24.00	29.00
	250	8-inch individual banded collar	3,941	234.00	24.00	29.00
		Add to the above prices for collars instead of inserted joint, where specified, per 100 feet		$ 11.00		
20	50	Reinforced inserted joint	3,059	147.00	27.00	33.00
	100	Reinforced inserted joint	3,346	169.00	27.00	33.00
	250	8-inch individual banded collar	4,580	266.00	27.00	33.00
		Add to the above for collars instead of inserted joint, where specified, per 100 feet		$ 13.00		

Above weights are approximate.

TABLE No. 22.—*Continued*

Diameter of pipe	Head	Kind of joint	Weight per 100 feet	Price per 100 feet, untreated and coated	Add per 100 feet for creosoted pipe	
					Uncoated	Coated
Inches	Feet		Pounds			
22	50	Reinforced inserted joint.....	3,360	157.00	30.00	36.00
	100	Reinforced inserted joint.....	3,761	186.00	30.00	36.00
	250	8-inch individual banded collar..	5,217	304.00	30.00	36.00
	Add to the above for collars instead of inserted joint, where specified, per 100 feet.....			$ 15.00		
24	50	Reinforced inserted joint.....	3,641	173.00	33.00	40.00
	100	Reinforced inserted joint.....	4,144	210.00	33.00	40.00
	250	8-inch individual banded collar..	5,854	346.00	33.00	40.00
	Add to the above for collars instead of inserted joint, where specified, per 100 feet.....			$ 17.00		

Above weights are approximate.

PIPE SYSTEMS.—As water becomes more valuable the unlined ditches will gradually give place to pipes in all parts of the West where highly profitable crops can be grown. The more economical use of water, the ease with which it can be applied and the greater assurance of better and larger yields render such investments safer than the ordinary run of farm outlays. In those parts of the West where the value of crop returns is neither high nor low but runs between $50 and $75 per acre, the farm owner must weigh the advantages to be gained by the cheapness of earthen ditches against a number of disadvantages. Among these may be mentioned the returns which might be derived from the valuable ground occupied by open ditches, the damage done by noxious weeds which grow on their banks, the loss of water by absorption, the structures required to span them, the heavy maintenance charge, the inconvenience of crossing and recrossing them with teams and implements, the difficulty of distributing water from such channels uniformly over the surface, and the resulting decrease in yield. Where the farm value of the crop is less than $50 per acre per annum earthen ditches are more economical.

Only the more valuable crops are irrigated in the humid region outside of the rice crop in the Gulf states and the eastern irrigator adopts the open ditch only as a last resort. He considers pipes the more efficient and economical for the following reasons: They are laid underground beneath the deepest plow sole, there is practically no loss in conveyance, and time and labor are saved in applying the water.

One of the first pipe systems installed in the West was for the Gage Canal Company in Riverside County, California. The water supply for the tiers of 40-acre tracts of this enterprise is taken from the Gage Canal in riveted steel pipes varying from 6 to 10 inches in diameter. These larger mains are connected with lateral pipes of the same material from 4 to 6 inches in diameter which convey the water to the highest corner of each 10-acre tract.

In more recent years, the quality of concrete pipe has been greatly improved and on account of its durability and safety under medium heads is now preferred for pipe systems. However, if success is to be attained care must be exercised in their installation. The design and construction of such systems involve experience and a practical knowledge of the making and laying of a high quality of concrete pipe coupled with a well-rounded training and experience in hydraulics. Some of the problems to be considered are herewith briefly outlined.

The basis of such a study is, in the large majority of cases, a topographic survey and map on which the contours may vary from 6 inches as a minimum to several feet depending on surface configuration and the purpose of the survey. Thus in the survey of main pipe lines in a hilly or mountainous country, contours 5 feet apart in vertical elevation usually meet all requirements, whereas more detailed surveys are necessary on the lands designed for farming purposes in order to subdivide the pipe system into suitable units and lay out a lateral system for each that will meet the irrigation requirements of the soil and crops.

Consideration must also be given to the friction losses in the pipe and the carrying capacity of each line.

Since the water carried is under pressure either from gravity or pumped heads, and since this pressure must not exceed safe limits, provision has to be made for standpipes, surge tanks and

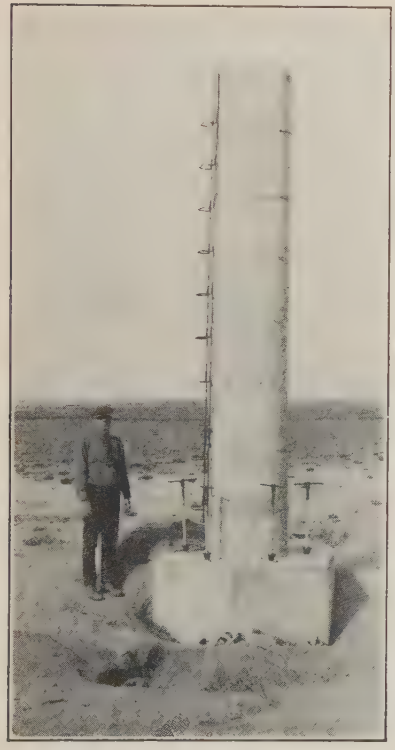


FIG. 30.—A surge tank placed above a division box.

FIG. 31.—A pumping plant with air vent.

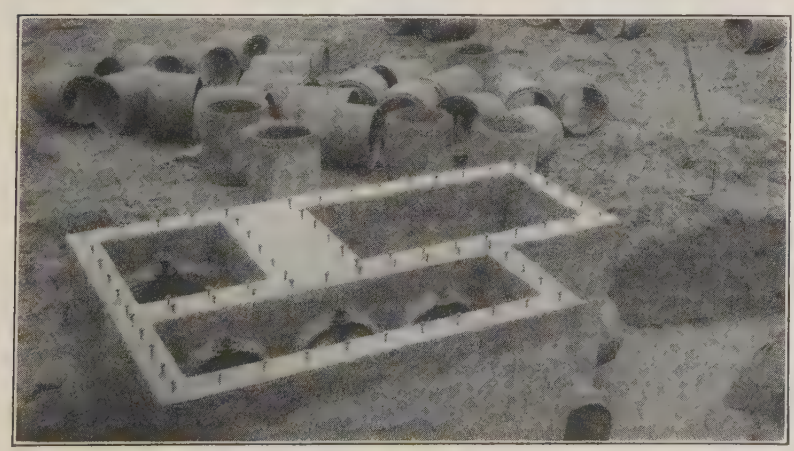


FIG. 32.—An uncovered division box similar to that shown in Fig. 30.

division boxes and gates. A surge tank placed above a division box containing six gates controlling as many concrete pipe lines is shown in Fig. 30. A pumping plant with air vent is shown in Fig. 31, and an uncovered division box in Fig. 32.

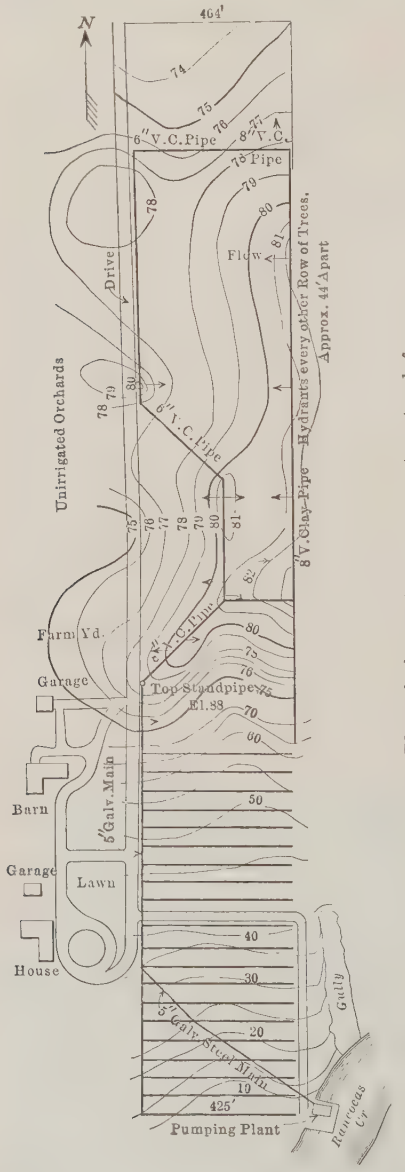


Fig. 33.—Plan of pipe system on an eastern truck farm.

In addition to that mentioned there is other equipment essential to the success of the system, such as settling basins and screens, overflow and relief stands, syphon standpipes, measuring devices, and distributing hydrants and valves.

Figure 33 shows the plan of the pipe system of the irrigated farm of Granville W. Leeds at Rancocas, N. J., as designed and installed by Milo B. Williams, Irrigation Engineer of the Department of Agriculture. In this system a 24-horsepower gasoline engine (Gray), driving a No. 3 American two-stage horizontal centrifugal pump, raises water out of Rancocas Creek to a maximum height of 88 feet. A 5-inch galvanized steel pressure main conveys the water from the pump to a standpipe. From there the water is distributed through small overhead pipes to about

9 acres which are irrigated by the overhead spray method. Under a pressure of 30 pounds per square inch at the nozzles of the spray pipes the plant discharges from 265 to 300 gallons per minute.

Leading out from the centrally located standpipe is another line of low pressure pipe of 8-inch vitrified clay which is reduced farther on to 6-inch pipe. These pipes are laid beneath the surface so as not to interfere with plows or subsoilers and fit into the topography of the tract (Fig. 34). Hydrants or stands are placed at the head of every other tree row, or approximately 44

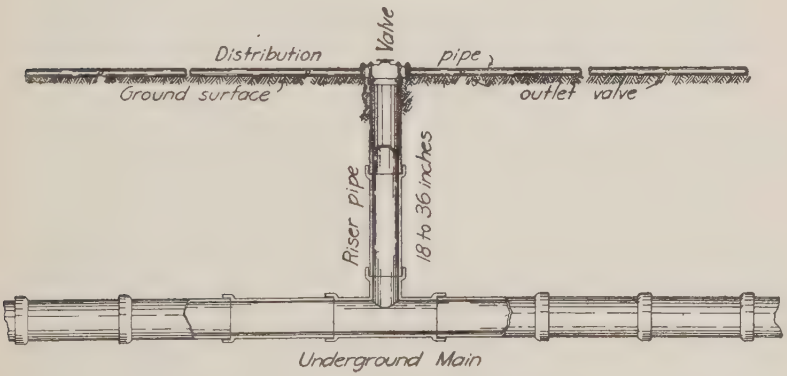


FIG. 34.—Underground pipe, hydrant, and distributor on an eastern truck farm.

feet apart. A portable distributing pipe, with openings spaced about 5 feet apart and controlled by special valves, is attached by canvas hose to each hydrant in turn for the irrigation of each strip between the hydrants. The capacity of the plant when water is conveyed from the standpipe through vitrified pipe and distributed over the surface in furrow irrigation varies from 300 to 350 gallons per minute. The cost of this plant complete was $3,440 or $123 per acre, but the extra returns from the irrigated area in the way of larger and better crops have rendered it a highly profitable investment.

16. Pumping Plants.—According to the census, there were in 1920, 29,458 pumping plants in the United States having a combined capacity of 36,270,000 gallons per minute and a capital investment of nearly $179,000,000.

Source of Water Supply.—Only a relatively small part of pumped water is derived from surface supplies such as streams, lakes, reservoirs and canals. The utilization of these is comparatively easy since all that is required is a direct connection between the pump and the water by means of a suction pipe.

By far the greater part of the water raised by pumping plants is found at varying depths beneath the surface. The water so found does not move as in streams freely from place to place in more or less large volumes. It is divided up into an innumerable number of small particles which are enclosed for the time being within the interstices of earth and rock. Some of these materials are either so fine in texture or else so dense that they virtually imprison the water within their mass. Other substances are more open in texture and these permit the slow passage of water through their open spaces. Such formations are termed water-bearing strata which receive and give off water to the extent of 20 to 30 per cent of their volume.

The percentage of open space in some material may exceed 40 per cent. When, however, the voids of coarse material such as gravel are filled with sand and those of the sand with silt or clay, the water-holding capacity of the material is greatly diminished and the amount of water which will pass through it in a given time is still further diminished. Whether the material composing a water-bearing stratum is of one kind, or of several, the amount of water which flows from it into a well, for example, is always less than the amount required for saturation. A certain percentage clings to each particle of silt, sand or gravel and cannot be dislodged by the force exerted by gravity. As a result of tests conducted by V. M. Cone and the writer in 1907 the fine sandy loam of Fresno County, California, contained 30.5 per cent of open space and gave off 22 per cent after being saturated. A clay-sand loam of the same locality contained 40 per cent of open space and gave off 25 per cent. In the coarser material penetrated by many wells the open space or porosity may be greater and such material may give off from a saturated mass fully 30 per cent by volume of water. Under some conditions this underground water moves in a generally horizontal direction down a given slope at a slow rate of speed—often not more than a few feet per day. This is true of beds of streams

which flow over porous material. When only a small part of this so-called underflow is withdrawn by pumps, the deficiency is speedily restored by the inflow. When, however, more water is withdrawn than the inflow can replenish the supply diminishes unless a low level is tapped.

Under other conditions there is little more than an up and down movement of the underground water caused by precipitation and floods on the one hand and deep percolation on the other. In such cases the withdrawal of water during an irrigation season usually lowers the water table but if this is restored when the pump ceases to run or at the close of the season or year no apprehension need be felt. It is only when the water table is permanently lowered as a result of pumping from season to season that a scanty or unreliable supply is indicated.

In calling attention to the longitudinal and vertical movements of underground water it is well to bear in mind that the water contained in any given water-bearing strata may be subjected to both movements in the same period of time.

Wells.—Ordinarily wells are dug by contract.[1] When the percussion method of drilling is used there should be a difference of at least 2 inches between the outside diameter of the sand bucket and the inside diameter of the casing and the sand bucket should have a steel shoe with a flap valve of as great an area as the bucket will allow. Where the contractor furnishes the well casing, starter section and other needed equipment, the kind, dimensions and quality of the material should be fully set forth in the contract.

Well drilling is usually paid for per foot of depth, the rate increasing with the depth in distances of 25 feet.

The most common type[2] for individual pumping plants in California is a drilled or bored well 10 to 16 inches in diameter, lined with one of the three following types of casing:

First: Standard steel screw casing.

Second: Single galvanized-iron casing 12 to 16 gage, with joints riveted together.

[1] Ewing, P. A., "Pumping from Wells for Irrigation," *Farmers' Bull.* 1404.

[2] Etcheverry, B. A. and Harding, S. T., "The Selection and Cost of a Small Pumping Plant," *Circ.* 117, *Univ. of Calif.*

Third: Double black steel casing, 12 to 16 gage, known as California stove-pipe casing, and used very generally in southern California. This casing is made of riveted steel sections 2 feet long placed with broken joints. The bottom of the casing consists of a starting section 15 to 20 feet long, made of triple thickness, riveted together with a steel shoe at the lower end.

The well and casing should extend into the water-bearing gravel far enough to give a perforated area equal to at least five times the cross-section area of the well. Slit perforations are made in the casing with an improved cutting tool. These perforations consist of six to eight slits made in each ring or circle, each slit being 12 to 18 inches long and 3/8 to 3/4 inch wide. A space of 4 inches is skipped after each set of perforations and another ring of slits offset with the adjacent ones is made. Slits should not be over 18 inches long in the case of stove-pipe casing. Special forms of perforations and wire windings are sometimes used.

General average costs for well boring (1923), exclusive of casing, in the San Joaquin Valley are about as follows:

Diameter of well in inches	Cost per foot of depth according to depth in feet			
	0 to 50	50 to 100	100 to 150	150 to 200
7	$0.90	$1.15	$1.50	$2.00
10	1.25	1.50	1.90	2.40
12	1.50	1.75	2.10	2.60
14	1.75	2.00	2.40	2.90

The cost per foot of steel stove-pipe casing is about as follows:

Diameter	12 gage	14 gage
7	$1.80	$1.35
10	2.50	1.75
12	2.90	2.05
14	3.30	2.35
16	3.75	2.65

The gravel-screen type of well has been successfully used in many localities of the West. In drilling the well, a temporary casing of much thicker metal than the ordinary casing is used. When the well is drilled a permanent casing well-perforated and 6 to 8 inches less in diameter than the temporary casing is inserted. Graded gravel of fairly uniform size is then poured into the annular space and as this process is continued the outer casing is gradually withdrawn.

In the rice belt, the hydraulic rotary method for drilling wells is the most common. The equipment usually consists of a derrick 16 feet square at the bottom tapering to 4 feet square at the top and about 40 feet high. The first operation after the derrick has been built over the site is to sink a test hole by using a 4-inch pipe in order to get a log of the well. A fish-tail bit is screwed into the lower end of the pipe and its cutting blade makes an opening somewhat larger than the pipe as both are revolved. Muddy water is then pumped into the pipe and is discharged under high velocities through two 1-inch openings in the bit at the lower end. The water carrying the borings then rises on the outside of the pipe to the surface. After the test hole has been drilled to the required depth the pipe is removed from the well.

The character of the materials, particularly those of the water-bearing strata, are known from the log, and suitable strainers and other equipment can then be ordered and transported to the site. The permanent well is then dug in very much the same manner as the test well.

PUMPS.—For low lifts, the horizontal centrifugal pump is perhaps the best type. Where there is little fluctuation in the water table and the lift is not over 25 feet they can be installed on the surface and belted or coupled direct to engines and motors. The same kind of pump can be lowered in a pit 10 to 15 feet below the surface in order to secure a safer suction and to adapt it to a somewhat higher lift.

For lifts between 20 and 75 feet the single-stage centrifugal pump is commonly installed. This kind of pump may be placed in the bottom of an open pit or shaft within safe suction reach of the water and if the water lift is stable it may be directly connected to an electric motor by vertical shafting.

Such installations are, however, rare in southern California on account of the seasonal and periodical fluctuation in the water table.

For lifts ranging between 75 and 150 feet the two-stage vertical centrifugal pump is the most common. The limit of 150 feet or less is due largely to the cost of the shaft. These shafts or pits are 6 by 8 feet or 5 by 7 feet when curbed with redwood and circular when curbed with concrete. The unit cost of the excavation increases with the depth.

Owing to the expense of digging a pit and lining it with concrete, which though more expensive than redwood is in the end more economical, the tendency in late years has been to install turbine or turbine centrifugal pumps for all lifts over 75 feet and thus dispense with the open pit.

For lifts ranging between 50 and 250 feet the type of pump known as the deep-well turbine is the most common. Its impellers or runners are encased in bowls operating within a well casing. The diameter of these casings may vary from 24 to 6 inches. The number of bowls depends on the lift, one bowl serving for 20 to 30 vertical feet. In case a well furnishes more water than can be pumped through a casing of a given size, the casing may be enlarged in the part where the bowls operate in order to install larger bowls of greater capacity. Apart from its first cost, the turbine pump possesses a number of advantageous features. It is particularly well adapted to wells having a fluctuating water table. It is also serviceable and efficient. During the past decade Byron Jackson Company, of Berkeley, Calif., has made and installed a large number of deep-well turbine pumps under a guaranteed efficiency of 75 to 85 per cent.

Where the quantity of water pumped is relatively small and the lifts high, the plunger pump is commonly installed. Pumps of this type may have one or more cylinders and be single or double acting. Two cylinder pumps are known as duplex and three cylinders, triplex. The relative capacities of a double-acting duplex pump, for example, and that of a double-acting one cylinder pump is as 3 to 1.

Power to Operate Pumps.—Excepting wind mills, the power generally used to operate pumps is either a gasoline engine or an electric motor. Neither the engine nor the motor should be

overloaded. Both should be designed to carry a load at least 10 per cent greater than the requirements. The power necessary to lift water is measured in horsepower and the energy required to lift 33,000 pounds 1 foot high in 1 minute is the equivalent of one theoretical horsepower. A pumping plant, however, is not a perfect machine, the useful work performed by it being usually between 25 to 75 per cent of the theoretical, depending on the kind of equipment used. In Table No. 23, giving the horsepower required to lift definite quantities of water stated heights a common average efficiency of 50 per cent of the pumping plant is allowed.

Should it be required to compute the horsepower required to lift Q gallons of water through a height of h feet at an efficiency of plant equal to E per cent it may be done by the equation—

$$\text{Number of horsepower} = \frac{Qh}{4{,}000E}$$

It should be noted that the letter h in the above formula includes the drawdown and the friction losses in suction and discharge pipes as well as the energy lost in valves and bends. All such are converted into the equivalent head in feet and added to h.

In comparing internal combustion engines with electric motors the former consume from one-eighth to one-sixth of a gallon of gasoline for each horsepower produced in an hour. The motor will produce an equal amount of power in nine-tenths of a kilowatt-hour, the kilowatt being equal to 1 1/3 horsepower.

The chief advantage which the engine possesses over the motor is that its fuel, in the form of petroleum or some of its products, can be obtained in most of the rural districts of the West, whereas electric current to operate motors is not available to a large percentage of western farmers. In localities fortunate enough to have cheap fuel oils and cheap electric power, the cost of pumping water per acre-foot, the lift being the same, would be somewhat less where a gasoline engine is used. On the other hand, in localities having reasonably cheap electric power and inferior or somewhat costly fuel oils, the electric motor has decided advantages in that it requires little attendance, and the fixed charges including depreciation, renewal, repair and maintenance are about 70 per cent of those of a gasoline engine.

TABLE[1] No. 23

Gallons per minute	Cubic feet per second	Elevation in feet															
		10	20	30	40	50	60	70	80	90	100	125	150	175	200	250	300
		Horsepower															
250	0.56	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50	15.62	18.75	21.88	25.00	31.25	37.50
300	0.67	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	18.75	22.50	26.25	30.00	37.50	45.00
350	0.78	1.75	3.50	5.25	7.00	8.75	10.50	12.25	14.00	15.75	17.50	21.88	26.25	30.62	35.00	43.75	52.50
400	0.89	2.00	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	25.00	30.00	35.00	40.00	50.00	60.00
450	1.00	2.25	4.50	6.75	9.00	11.25	13.50	15.75	18.00	20.25	22.50	28.12	33.75	39.38	45.00	56.25	67.50
500	1.12	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	31.25	37.50	43.75	50.00	62.50	75.00
600	1.34	3.00	6.00	9.00	12.00	15.00	18.00	21.00	24.00	27.00	30.00	37.50	45.00	52.50	60.00	75.00	90.00
700	1.56	3.50	7.00	10.50	14.00	17.50	21.00	24.50	28.00	31.50	35.00	43.75	52.50	61.25	70.00	87.50	105.00
800	1.78	4.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00	40.00	50.00	60.00	70.00	80.00	100.00	120.00
900	2.01	4.50	9.00	13.50	18.00	22.50	27.00	31.50	36.00	40.50	45.00	56.25	67.50	78.75	90.00	112.50	135.00
1,000	2.23	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	62.50	75.00	87.50	100.00	125.00	150.00
1,250	2.78	6.25	12.50	18.75	25.00	31.25	37.50	43.75	50.00	56.25	62.50	78.12	93.75	109.38	125.00	156.25	187.50
1,500	3.34	7.50	15.00	22.50	30.00	37.50	45.00	52.50	60.00	67.50	75.00	93.75	112.50	131.25	150.00	187.50	225.00

[1] Extracted from *Farmers' Bull.* 1404, "Pumping from Wells for Irrigation," by PAUL A. EWING.

While the large majority of pumping plants installed and operated for the purpose of furnishing water for irrigation have proved satisfactory a certain percentage have failed or partially failed. These have been caused by small returns from the crops irrigated, operating pumps under too high lifts and correspondingly high costs per acre served, permanent lowering of the water table in wells, installing unsuitable equipment and other features of the investment. Before spending money on a pumping plant a close estimate should be made of the cost of the water and the value of the crops which it is designed to irrigate. Consideration should also be given to the adequacy and reliability of the water supply and the purchase of a plant that will fulfil the necessary requirements in an efficient manner.

CHAPTER IV

METHODS OF PREPARING LAND AND APPLYING WATER

17. The Removal of Native Vegetation.—In arid America few places are so barren as not to produce plants of some kind, and the first step in preparing land for irrigation is the removal of this native vegetation. When this consists of native grasses, low cacti, or rabbit brush it can be plowed under or removed without much extra expense but when it consists of large sagebrush, greasewood, mesquite or other plants of shrubby growth the cost may be considerable. Still costlier is the removal of junipers, pines, or other trees—sometimes of considerable size—which grow in some of the less arid sections where irrigation is practised.

Sagebrush.—Of all the desert plants, sagebrush is the most widely distributed. It covers thousands of square miles of the Rocky Mountain and Pacific Coast states and various methods have been employed in removing it from irrigable land.

Instances are recorded where sagebrush has been killed by irrigating the land heavily for a season. The wetting of the soil causes weeds and grass to grow and when these are dry they are set on fire and in burning the dead sagebrush is consumed at the same time. Such a practice, however, cannot have a wide application, and where land and water are both valuable, it is not a practice to be recommended.

Sagebrush can be quite easily broken off at the surface of the ground, and in clearing large tracts, one of the most common practices is to break the brush by dragging a railroad rail over it, using a strong team at each end of the rail. The rail is dragged twice over, the second time in the opposite direction to the first. Sometimes if a rail is not available, a heavy stick of timber is used as a substitute, but with somewhat less satisfactory results. Though the rails are very commonly used straight, it is claimed they are more effective in tearing out and breaking off the brush if bent into a V-shape. By using a rail in this way, nearly all

the sagebrush is broken off, and what little remains can be easily cut by hand with a mattock.

After railing, the sagebrush is either raked into windrows or piled by hand and burned. In districts where the soil is subject to blowing it is sometimes left in windrows 30 to 50 feet apart for a year or two to serve as a windbreak while the intervening space is placed under cultivation. The cost of clearing land by the method of railing varies with the density and size of the sagebrush but contract prices in the Northwest during recent years have ranged from about $3 to $7 per acre, which includes burning the brush.

Heavy two-bottom gang plows drawn by six large mules have been used with success in removing sagebrush in the Yakima Valley, Washington. This work was done by contract at $4.50 per acre. Five acres of plowing was an average day's work. In addition it cost $2 per acre to gather up and burn the brush; making the total cost of clearing and breaking $6.50.

In Colorado, sagebrush has been plowed out with a gang plow and steam traction engine.

Under certain conditions it is often more economical or satisfactory to remove the sagebrush by hand grubbing. For this work a sharp mattock is used and the brush is cut at the surface of the ground. This is most easily accomplished when the ground is frozen. Where the growth is of average size and density, one man can grub about 1 acre a day. To gather up and burn the brush will require possibly half a day more, making the cost of clearing by hand, with wages at $3 per day, about $4.50 per acre.

Greasewood.—This is another shrubby plant having a wide range of distribution from the upper Missouri River region south to Mexico, and west to the Sierra Nevada and Cascade Mountains. Its presence on the plains is not so general as sagebrush. It is often found and seems to thrive best on soils more or less impregnated with alkali and its presence for this reason is usually looked upon with suspicion. A height of 8 feet or more is sometimes attained by this plant.

Mesquite.—Mesquite is found in the far Southwest from central Texas to eastern California. According to its surroundings it varies from straggling spiny shrubs to a widely branched tree

50 feet high and 3 feet in diameter. The latter size is attained only in the rich valleys having an abundance of moisture. On the arid plains, as a shrub only 2 or 3 feet high, the roots may extend to water at a distance of 60 feet or more.[1] Greasewood and mesquite such as is usually found on lands suitable for irrigation can be cleared by the same methods commonly employed in the removal of sagebrush.

Large trees are not commonly found in regions where land is prepared for irrigation, but in some localities, junipers, pines or other trees of considerable size have to be removed. As a rule, all trees large enough for wood or saw timber are removed first, then the smaller trees are slashed, and, when dry, burned together with the tops of the larger trees. Small pine stumps rot quickly, and within a year or two after the cutting those 4 to 6 inches in diameter may often be removed by a direct pull with a good team. For stumps of larger size, some one of the many types of stump pullers is employed and more or less dynamite and stump powder are used to split or blow out the ones too big to be handled readily with the pullers. The cost of removing trees and stumps varies widely according to the kind of trees and the number to the acre. In clearing several thousand acres of pine land from which the saw timber and wood has largely been removed, in the vicinity of Spokane, Wash., the cost ranges from $40 to $75 per acre. The Hercules stump puller is used mainly, and this is supplemented by powder. In parts of British Columbia, where land is cleared for irrigation without making any use of the wood or saw timber, the cost per acre for removing trees and stumps runs from $75 to $150 per acre.

18. Preparing the Surface for Irrigation.—Following the removal of native vegetation, land to be irrigated usually requires grading or smoothing in order that water may be distributed or spread over it uniformly with a minimum of labor and expense. In some parts of the West large areas of land are found which are naturally smooth, and consequently require very little grading preparatory to irrigating, while in other sections the natural topography of the land is so irregular that the work involves a heavy expense. There is frequently wide variation also in the requirements of different tracts in the same locality. By level-

[1] BERGEN AND DAVIS, "Principles of Botany," p. 27.

ing or grading is not meant the reduction of the land to a level surface, as this would in most places be not only impracticable but undesirable. Except where the land is very flat, grading as a rule involves only the removal of knolls and hummocks which interfere with the flow or spreading of the water, and the filling of depressions into which the water would collect to a detrimental extent. The aim in grading should be to obtain plane surfaces. These, however, may have little or much slope according to the local conditions found.

It pays to prepare the surface of fields for rapid and efficient irrigation. Measured in money invested for the betterment of the irrigated farm, the difference between a field poorly prepared and one well prepared would not exceed as a rule $12 per acre.

The benefits to be derived from this investment which costs in interest about $1 per acre per annum may be grouped under the following heads:

1. Larger yields of crops.
2. Better quality of crops.
3. Reduction in the waste of water.
4. Saving time and labor in irrigating.
5. Keeping the soil productive.
6. Enhancing the value of the farm.

If the soil is fairly uniform for a considerable depth, as it is in many arid districts, considerable of the surface layer may be removed without permanently impairing the productivity of the land. But if coarse gravel or some other form of unproductive subsoil occurs within a foot or two of the surface, a compromise must be made between the advantages of good grading and the disadvantages of poor soil. Under such conditions, it may sometimes be practicable, in a limited way, to move the surface soil to one side, remove so much of the poor subsoil as required and then replace the surface soil. It may be easier and better to modify the usual method of irrigation to suit the land, than to modify the land to suit the usual method of applying water. Grading is frequently carried too far on this kind of soil but even under the most unfavorable conditions some improvement of the surface is usually possible.

The cost of preparing the surface after clearing runs all the way from a few dollars to $50 or more per acre, depending mainly

on how much dirt has to be moved. If the land has not been broken up in removing the native vegetation, the first plowing, which as a rule can be done with an ordinary strong plow and three or four horses, will cost from $3 to $4.50. This, however, is about as far as any itemizing of cost can be carried. In some parts of the West where land is held at $150 to $300 per acre, a cost of from $25 to $45 per acre for grading is not unusual, nor is it considered excessive. This, however, is higher than the average cost of such work.

If it is necessary to move much earth and the haul is short, one of the best implements for the purpose is the buck-scraper (Fig. 35). In its simplest form it consists of a 2-inch plank with a steel shoe on the cutting edge and a tailboard for holding the plank in position while filling, and for controlling the angle of it while spreading the dirt. Scrapers of this type have been

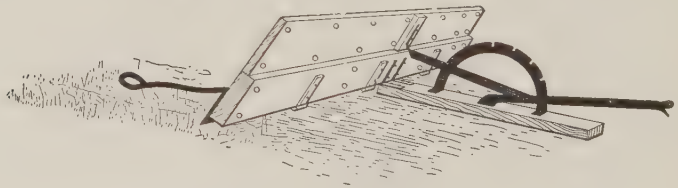


FIG. 35.—Buck-scraper.

made in lengths up to 24 feet but the size commonly used for four horses is 8 feet long and 2 feet wide. The four-horse size is securely ironed and bolted together and can be made by the local blacksmith or on the farm at a cost of about $20. Some scrapers have a lever attached to the tailboard so that the scraper can be set at the desired angle in loading or spreading.

In parts of California a modified buck-scraper or planer has been found especially useful on a slightly uneven ground. This consists of a base made of 4 by 12-inch plank 14 feet long and a back 2 inches thick, 18 inches high and 12 feet long. The base and back are held together by the extension of the steel plate with which the cutting edge and bottom of the base plank are shod and by iron straps on the front side of the upright plank. Footboards are bolted across the base plank which extends a foot beyond the back at each end. Four mules are used at each end

of the planer, the hitch being made to the base plank below the footboards. The drivers regulate the action of the implement by shifting their positions forward or backward on the footboards.

If the grading is heavy and the haul long, the "Fresno" scraper (Fig. 36) is the most satisfactory implement. This is a steel scraper 4 to 8 feet long which works on the same principle as an ordinary "slip." A single steel handle about 4 feet long, attached at the middle of the back of the scraper, serves both as a means of regulating the dip in loading, and in dumping and spreading the load. Usually a short piece of rope is attached to the end of the handle to facilitate turning the scraper back into position preparatory to loading. The common sized "Fresno" is pulled by four horses, but a smaller size suitable for two horses is also made.

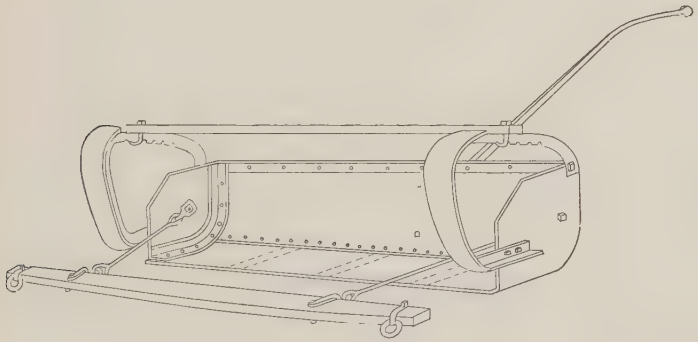


FIG. 36.—Fresno scraper.

The scrapers so far described are used for rapid movement of earth, and are not especially adapted to the work of making a finished surface. This is done with some form of rectangular leveler, the function of which is analogous to that of the long "jointer" plane used by a carpenter to smooth the edge of a board after the prominent humps have been removed with a short "jackplane." These levelers are made in many sizes and proportions to suit the local requirements, but the principle of their use is for all the same. The leveler is intended to remove the minor irregularities of the surface by spreading the earth left in bunches by the scraper, and by filling the slight depressions

which ordinarily cannot be detected with the eye. After having been properly leveled with a leveler the field should present a smooth, plane surface.

The rectangular float or "box leveler" generally used is essentially a frame about 6 feet wide and 14 to 24 feet long, made of 2-by 8-inch or 2-by 10-inch planks set on edge; several crosspieces being used in addition to the ones at the ends. The framework should be diagonally braced on top, and well spiked or bolted together. The cross-pieces should be faced on the front side with steel or iron plates. A footboard placed on top, in the middle, parallel to the long side affords a place for the driver to stand. The hitch is made so that the leveler is drawn lengthwise and the action of the leveler can be regulated to some extent by the driver shifting his position forward or back. The number of horses required varies with the size and weight of the implement. Four to six are commonly used, but more are sometimes put on very large levelers. In the Imperial Valley, California, rectangular levelers have been made in sizes up to 12 by 30 feet, requiring 16 horses and an operator in addition to the driver. A rectangular leveler suitable for use with two to four horses is a very inexpensive implement that can be made on the farm, and it will often be of value in smoothing plowed fields in years succeeding the original grading.

Graders or levelers of other types are used in some localities. Some of these are patented machines. These cost more, and farmers generally prefer the less expensive homemade ones which are very satisfactory.

When preparing the surface for irrigation, sufficient soil to allow for settling should be placed in depressions of any considerable size, and before the field is seeded to permanent meadow or other long term crops, it is well to first irrigate it thoroughly. The application of water will settle the soil of fills, and disclose any need of further grading, more or less of which is usually required to put the surface in perfect shape.

In 1922, contracts were let for the clearing, leveling and ditching of a number of tracts of land on the Wapato project in the state of Washington. The acreage in each tract and the cost per acre of clearing, leveling and ditching are given in Table No. 24.

TABLE No. 24

Acres	Cost per acre			
	Clearing	Leveling	Ditching	Total
80	$6.00	$10.00	$3.00	$19.00
240	6.00	12.00	2.00	20.00
80	7.00	10.00	3.12	20.12
80	5.00	5.00	1.00	11.00
160	7.00	10.00	3.00	20.00

19. Furrow Method of Irrigation.—This method is used to irrigate crops which are grown in rows, such as orchards, small fruits, root crops, corn, cotton, sugar cane and vegetables. It is adapted to a wide variety of soils and surface slopes. However, very porous soils should be watered if possible by some other method on account of the waste of water by deep percolation and water in furrows moves too slowly on flat slopes. The essential features of furrow irrigation are the head ditch, flume or pipe from which the water is distributed and the furrows. Since large heads of water are not required, the capacity of the head ditch usually varies from 1/2 second-foot to 2 1/2 second-feet.

EARTHEN HEAD DITCHES.—The cheapness and ease of construction of such ditches are their only redeeming qualities and account for the large number used. The labor involved in making openings in the lower ditch bank with a shovel and the lack of uniformity in the distribution of water are serious drawbacks. A skilful irrigator may adjust the size and depths of the openings in a ditch bank so as to secure a fairly uniform flow, but constant attention is required in order to maintain it. If the water is permitted to flow unattended for half an hour, the distribution is likely to become unequal. The banks of the ditch absorb water and become soft, and as the water rushes through the openings, erosion enlarges them, permitting larger discharges and lowering the general level of the water in the ditch so that other openings may have little or no discharge. Even if it were possible to divide the flow of the ditch equally between a certain number of furrows the difficulty would not be overcome, because the number of

divisions would invariably be too small. In using such crude methods it is difficult to divide a stream of, say, 40 miner's inches, into more than about ten equal parts; but good practice frequently calls for a flow in each furrow of from one-fifth to three-fourths of a miner's inch, which cannot be secured by this method.

One of the most serviceable homemade implements for making head ditches is the crowder.

Short tubes or spouts have been used in head ditches to divert small quantities of water to furrows. These tubes usually are made of wood, but pipes made of clay, black iron, galvanized iron and tin are used occasionally. A cheap and serviceable tube may be made from pine lath, such as are used for plastering. The 4-foot lengths are cut into two equal parts and four of these pieces are nailed together to form a tube, as shown in Fig. 37. One of these tubes when placed with its center 2 inches below the surface of the water in the head ditch discharges nearly three-quarters of a miner's inch of water, and if placed 4 inches below the surface will discharge more than 1 miner's inch. In southern Idaho the

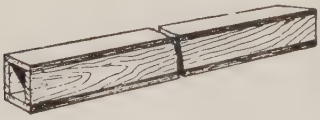


FIG. 37.—Lath pipe for ditch bank.

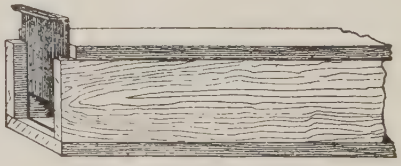


FIG. 38.—Tube for ditch bank made from half-inch boards.

lumber mills manufacture a special lath for this purpose. It is 1/2 inch thick, 2 inches wide and 36 inches long. If such tubes when thoroughly dry are dipped in hot asphalt they will last much longer. In some of the deciduous orchards of California a still larger wooden tube or box is used. Figure 38 represents one of these. It is made of four pieces of 3/4 by 3 3/4-inch redwood boards of the desired length. The flow through this tube is regulated by a cheap gate, consisting of a piece of galvanized iron sliding in grooves.

The farmers who live near a manufacturing town or city can often purchase at a low figure pieces of wornout and discarded piping varying from 3/4 to 2 inches in diameter. Such pipes when cut into suitable lengths make a good substitute for wooden

spouts. Tin tubes 1/2 inch in diameter and of the proper length have been used with good success. In compact soils, through which water passes very slowly, the furrows must be near together and under such conditions small tin tubes are to be preferred.

In making use of tubes of various kinds to distribute water to furrows it is necessary to maintain a constant head in the supply ditch. This is done by inserting checks at regular distances. These distances vary with the grade of the ditch, but 150 feet is not far from being an average spacing. In temporary ditches the canvas dam is perhaps the best check, but in permanent ditches it pays to use wood or concrete. An effective wooden check is shown in Fig. 39. In this the opening is controlled by a flashboard which may be adjusted so as to hold

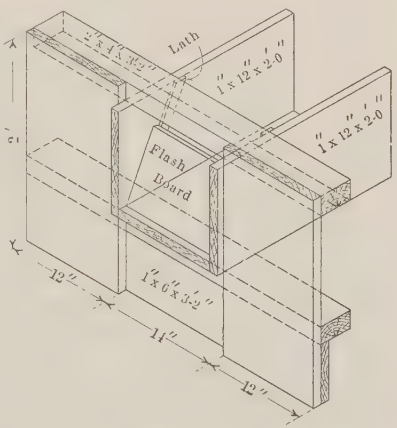


FIG. 39.—Check box in head ditch.

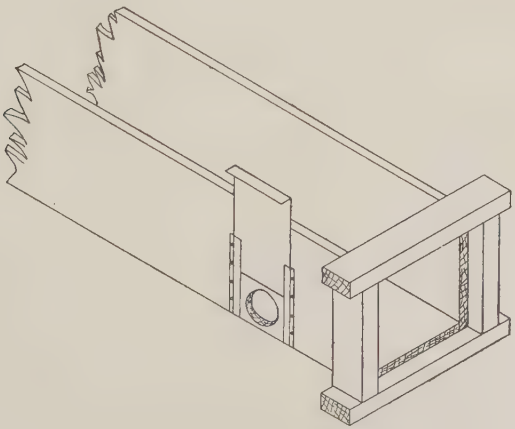


FIG. 40.—Common form of wooden head flume.

water at any desired height and at the same time permit the surplus to flow over the top to feed the next lower set of furrows.

Head Flumes.—In the Northwest, where durable lumber can be purchased at reasonable rates, timber flumes are often used to distribute water to furrows. The length of the section varies from 12 to 20 feet, 16 feet being the most common. The bottom width runs from 6 to 12 inches, while the depth is usually 1 to 2 inches less. Redwood lumber 1 1/4 inches thick is perhaps the best for the bottom and sides, and joists of 2- by 4-inch pine or fir are commonly used for yokes which are spaced 4 feet centers. Midway between the yokes auger holes are bored and the flow through these openings is controlled in the manner shown in Fig. 40. A 2-inch fall for each 100 feet may be regarded as a suitable grade for head flumes, but it often happens that the slope of the land is much greater than this, in which case low checks are placed in the bottom of the flume, at each opening.

A head flume composed of cement, sand and gravel costs as a rule about twice as much as a wooden flume of the same capacity, but the early decay of wood, especially if it comes in contact with earth, may make the cement flume cheaper in the end. By means of a specially designed machine, which is patented, cement mortar composed of one part cement to about six parts of coarse sand is fed into a hopper and forced by lever pressure into a set of guide plates of the form of the flume. Such flumes are made in place in one continuous line across the upper margin of the field. After the flume is built and before the mortar has become hard, small tubes from 3/4 to 1 1/2 inches in diameter, the size depending somewhat on the size of the flume, are inserted in the side next to the field. The flow through these tubes is regulated by zinc slides. Flumes of this kind are made in five sizes, the smallest being 6 inches on the bottom in the clear and the largest 14 inches.

Pipes and Stands.—Head flumes being placed above ground interfere with the free passage of teams in cultivating, irrigating and harvesting the crop. Dead leaves from shade and fruit trees also clog the small openings in the flumes. These and other objections to flumes have led to the extensive use of pipes, especially in California. Figure 41 shows a concrete head pipe 8 inches in diameter laid with its top 12 inches below the ground

surface. The cut likewise shows one of the larger stands 16 inches in diameter with its valve through which water is admitted to the head pipe and the smaller distributing stand with its small valves through which water flows to the furrows.

Where steel or wood pipe is used to carry irrigation water, there is no necessity to make provision for relief of pressure, since such pipe is strong enough to withstand the pressure common to pipe systems of farm irrigation. This is not true of concrete pipe, especially the inferior concrete pipe built on the Pacific Coast for distribution of water in orchards prior to 1920. For this inferior pipe overflow stands were installed at fixed intervals down the grade, the stands being high enough to back water up to the next

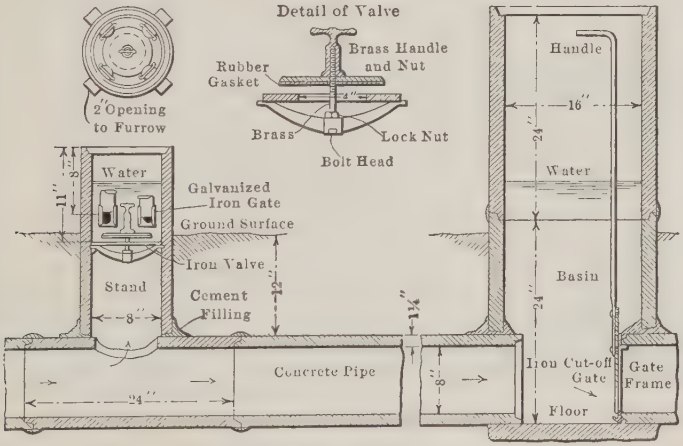


FIG. 41.—Concrete head pipe, with stands, valves, etc.

relief stand above it, distributing hydrants being placed between the two relief stands as shown in Fig. 42. Since 1920, a marked improvement has been brought about in the manufacture of concrete pipe and the higher pressures which the modern pipe can safely withstand has made it possible to control pressures largely by valves and the use of a limited number of high relief stands.

FURROWS.—The depth, spacing and length of furrows depend mainly upon the character of the soil and subsoil, and the kind of crop irrigated. Topography and climate are of secondary importance. Furrows in tight, clay soil should be shallow, spaced

near together and of considerable length. Water penetrates slowly through such material and it is necessary to run a small amount for a long time in order to moisten the soil in the root zone of plants. Very porous soils of which blow sand is an extreme type are not well adapted to the furrow method of irrigation. If used in this material the furrows should be short in length and large in carrying capacity, so that the water may reach the end of the furrow in the shortest possible time and then be turned off.

FIG. 42.—Concrete pipe and overflow stands.

In growing shallow-rooted crops or in irrigating a shallow soil, the furrows should likewise be shallow. In growing such crops, however, it is well to bear in mind that the top layer of soil in an arid climate cannot be utilized for the nourishment of plants, for the reason that the heavy evaporation robs it of its available moisture. The depth of soil which is so affected varies from a few inches in the northern tier of western states to nearly 12 inches in the southern tier. In all cultivated crops the grower should figure on reserving the required depth of the top soil to be used as a sort of blanket or dry soil mulch covering to protect the moist soil beneath. It is unfortunate that the soil so reserved is the most fertile, the best aerated, and the most easily worked

soil of the field. In the experiments conducted by Dr. Loughridge, of the University of California, and the writer in 1905 in the citrus orchards of Riverside, Calif., it was shown that irrigation by means of a large number of shallow furrows followed by shallow cultivation was not good practice for that particular locality, soil and crop. During the dry, hot months of summer little free moisture was found in the upper 12 inches of soil prior to the time of irrigating. In other words, the moisture content of the top foot of soil was wholly inadequate to support plant life. As a result the tree roots found in this layer of soil were either withered or unable to perform their proper function. Orchardists who permitted the roots of trees to be lured near the surface during the winter rains were disappointed in learning that the trees after expending a part of their vital force in developing roots to occupy this new feeding zone were damaged

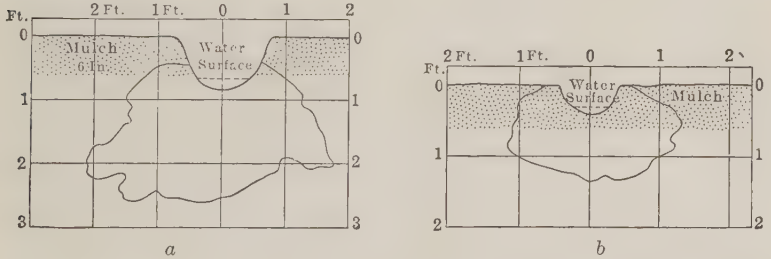


FIG. 43.—(*a*) Distribution of water from deep furrow. (*b*) From shallow furrow, in same time.

by the subsequent withering or inaction of part of the root system so formed. Modern practice in orchard irrigation in southern California aims to prevent, by frequent and deep cultivation, the formation of roots near the surface. This results, as has been stated, in setting aside the top layer of soil in order to conserve and make more constant the moisture content of the remainder. The depth of this top layer varies with different conditions. A depth which would suffice for the low temperature and light evaporation of the Bitterroot Valley, Montana, might have to be increased 100 per cent in the Salt River Valley in Arizona. The same principles, however, apply to both locations.

From the foregoing it is observed that the top layer of dry soil mulch should not be irrigated. This can be accomplished in

part at least by the use of deep furrows. Figure 43*a* shows the distribution of the water in 7 hours from a furrow 10 inches deep and Fig. 43*b* a similar distribution from a furrow 5 inches deep in the same time. From the former it will be seen that little of the mulch is moistened and that the water has a wide distribution at a depth of 2 feet below the surface where the most roots are to be found, whereas in the latter nearly one-half of the water applied has found its way into the soil mulch to be speedily dissipated by evaporation.

The views shown in Plate I convey some idea of modern practice in the furrow irrigation of orchards in California.

Length of Furrows.—In porous soils, the length of furrows should not exceed 200 feet. Even in reasonably tight soils it is seldom economical to exceed a length of 660 feet. These limitations as to length are made for the purpose of securing a more even distribution of the water. The main defects of a long furrow one-eighth to one-quarter of a mile in length are the overirrigation of the subsoil near the head ditch or flume if the soil is porous and the flooding of the lower portion of the field if the soil is impervious. A good arrangement in medium soils is to divide a 40-acre tract into three belts by as many head ditches, thus making the furrows in each belt or field 440 feet long.

In determining the extent of deep percolation from furrow irrigation in a citrus orchard of Riverside, Calif., Loughridge and Fortier found that water from an irrigation penetrated to a depth of 26 feet near the upper end of the furrow and barely sufficed to moisten the root zone in the lower half of the orchard.

The distribution of water conveyed by furrows in the soils of various types in given periods of time was also investigated by Loughridge and Fortier and the results showed a wide difference in depths of penetration. The minimum depth in 24 hours was 6 inches and the maximum 30 inches. The effect of any impervious layer such as hardpan on the depth of water penetration was to increase the lateral spread but diminish the depth.

In irrigating crops by the furrow method, the furrows, with few exceptions, are made parallel to the rows. In the case of mature orchards, however, cross-furrowing is gaining in popular favor. The purpose of this modification is to moisten the dry spaces shown in Fig. 44. Each space in mature orchards may contain

FIG. A.—Furrow irrigation of a cherry orchard in Santa Clara valley, California.

(*Facing page 122*

PLATE I

FIG. B.—Furrow irrigation of orchard in Wenatchee, Wash.

from 100 to 160 square feet which usually becomes so dry that it is of little value as a feeding ground for roots. In order to moisten these dry spots, first, cross-furrows, indicated by the dotted lines in Fig. 45, are made, then the regular furrows, after which the zigzag system, as shown, is completed by a little hand-work with a shovel. Since the flow in each furrow can be quite accurately gaged by the slide on the stand, it is customary to turn in more water to the furrows which feed the cross-furrows. Cross-furrowing is sometimes resorted to on steep slopes to lessen

Fig. 44.—Furrow irrigation showing dry places.

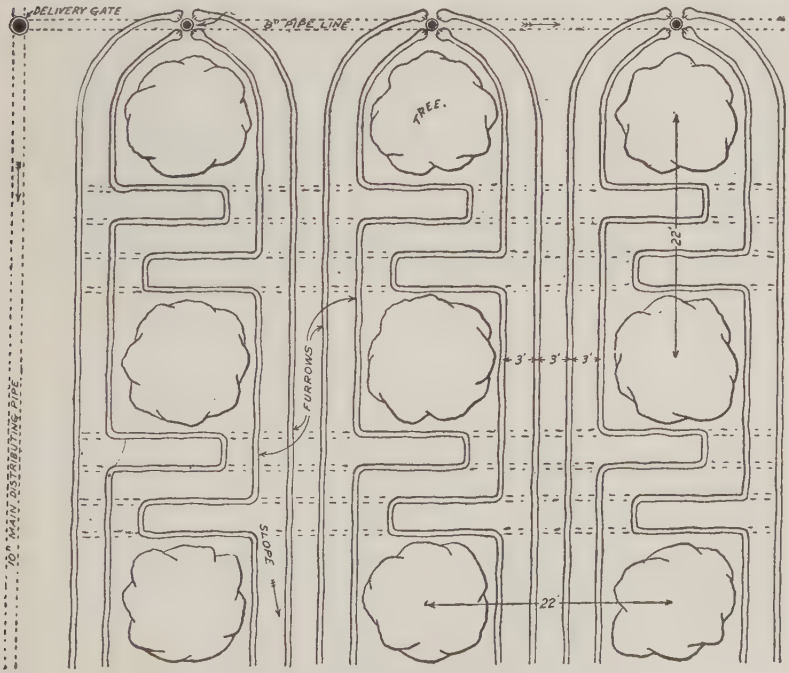


Fig. 45.—Plan for laying out zigzag furrows.

the velocity of the water and thus prevent erosion. It is also made use of in the lower portions of orchard tracts to secure as deep

a penetration of moisture as occurs from the direct furrows on the upper portions.

On steep hillsides, perennial crops are sometimes planted on grade lines to suit the flow of water in the furrows. A suitable grade for ordinary soils is 11/2 per cent., *i.e.*, the fall is 18 inches per 100 feet.

20. Corrugation Method of Irrigation.[1]—The corrugation method of irrigation is a modification of the older and more widely known furrow method. It had its origin in the northwestern states and is now generally used there in watering uncultivated crops such as small grains and hay. Some means of flooding the entire ground surface is usually employed elsewhere for the irrigation of such crops; but owing to the rough topography, peculiarities of soil, methods of planting and harvesting crops, and the established practice of using small streams of water for irrigating, the corrugation method has come into general favor in the Northwest.

The principle involved in the corrugation method is that of subirrigation accomplished by allowing small streams of water to flow through a series of narrow, shallow furrows or corrugations long enough to permit the horizontal seepage from adjacent irrigated corrugations to meet, thus resulting in a thorough wetting of the soil between the corrugations. Three general features of the method should be considered in planning for irrigation by means of corrugations, these being the field ditches, the structures and the corrugations themselves.

Field Ditches.—The field ditches for this particular method of watering crops are small, carrying from 1 to 2 second-feet and are made in a manner similar to those described in a former chapter.

Structures.—These comprise headgates or turn-outs, measuring devices, flumes, checks and wooden spouts. None of these except checks differs in any marked degree from similar structures used in other methods of irrigation and for that reason they need not be described.

Corrugations.—Corrugations are essentially small furrows (Fig. 46) spaced from 16 to 48 inches apart depending on the

[1] The greater part of the information given in this article is taken from *Farmers' Bull.* 1348, "The Corrugation Method of Irrigation," by James C. Marr.

soil type. When carrying the proper stream of water, they are supposed to irrigate the soil thoroughly, principally by a capillary movement of the moisture. Theoretically, the stream used in the corrugations is just enough to supply water for uniform absorption on all sides of the corrugation and throughout its length to a depth not greater than the lowest plant rootlets without any waste at the lower end. The length of corrugations and the distance between them should be such as to accomplish this result. Usually the best practice to follow in making corrugations is to have them neither deeper nor wider than is necessary safely to confine the stream. Shallow furrows are most effectual

FIG. 46.—Corrugations as made in southern Idaho.

in spreading moisture horizontally at the ground surface. In the irrigation of trees and deep-rooted crops, such as alfalfa, the farmer not infrequently uses deep corrugations with the idea of wetting the subsurface rather than the surface soils, but allows the water to run until moisture shows on the surface. This usually will require a much longer time of application than should be necessary to irrigate the crop properly and will result in a waste of water through deep percolation. Under ordinary conditions corrugations 4 inches deep and 5 or 6 inches wide will be most satisfactory.

The proper distance between corrugations for a particular soil is double the horizontal distance through which moisture will move away from the water line during the time required for the

downward moving moisture to reach the maximum depth of plant rootlets. For example, the feeding rootlets of an alfalfa plant extend an average depth of 6 feet into the ground. If the vertical movement of moisture downward is six times as rapid as the horizontal movement, then soil will be moistened for a distance of 1 foot on each side of a corrugation during the time required for wetting the soil to the proper depth. In this case corrugations should be spaced at intervals of 2 feet. Lava-ash soils have almost the characteristics of blotting paper, so rapid is the horizontal movement of moisture and so far does the movement extend. In very heavy soils this horizontal seepage is so slow as to render the use of corrugations ineffective as a means of irrigation. In sandy soil the downward movement of moisture is so much greater than the horizontal movement that the loss of water through deep percolation prohibits this method. The presence of hardpan or some other stratum which will halt the downward movement of water is a favorable condition for widely spaced corrugations. In general practice the interval between corrugations varies from 16 inches to 3 or 4 feet with the most usual spacing about 20 inches.

In determining the spacing, the irrigator often allows labor and expense to have greater weight than the requirements of the soil. The result is that wide intervals between furrows and slow rates of irrigation are used with consequent overirrigation and a probable development of need for drainage. The simple experiment of running water for different lengths of time through separate corrugations and then excavating a trench across them, exposing the area of dampened soil, will aid the irrigator in determining the proper spacing of corrugations and the length of time that water should be allowed to remain in them for any given soil condition. Since the watering, cultivation, and growth of crops very frequently bring about a change in the physical properties of a soil and subsoil, it is advisable to redetermine the proper spacing of corrugations and the proper rate of irrigation after land has been farmed for 5 or 6 years.

The length of corrugations varies from 150 to 1,200 feet, but more often they are from 300 to 600 feet. Generally, the longer the corrugation, the more inefficient it is in uniformly distributing irrigation water throughout its length, and consequently it should

always be as short as practicable. Under ordinary conditions 300 to 400 feet represents good practice, but shorter corrugations are needed for either very steep or comparatively level lands and it may be advantageous to use longer furrows for soil which absorbs water slowly. On very steep slopes an exceedingly small stream is used in order to reduce soil erosion to the minimum and this stream will not travel very far before being absorbed. Under such conditions the length of corrugations is limited to 200 feet or less. Likewise, for comparatively level land, fields must be short to confine streams to the small furrows and water the land in a reasonable time.

Slopes giving the least difficulty in the operation of the corrugation method are from 1 to 2 feet per 100 feet, but slopes as great as 15 or 20 feet per 100 feet may be irrigated properly by this method. In fact, the greatest advantage of the corrugation method is its adaptability to steep, rough land. For comparatively flat land some method of flooding is much to be preferred, but, whatever the grade, it is advisable to run the water in the direction of maximum slope, since any appreciable side slope is likely to cause the breaking over of one stream to the next. A field may be terraced to take up the side slope and so provide a more moderate grade, but the expense of terracing, the waste of land, the difficulty of keeping the steep slopes between terraces free from weeds, and the added difficulty of harvesting crops make the use of the original slope preferable.

Land is corrugated usually just after the seeding of a crop, a horse-drawn implement capable of making from two to four furrows at one time being used. The steel corrugator is a manufactured implement and is particularly useful for recorrugating old alfalfa fields, because it is equipped with a vertical knife and a shoe on the runner which cuts through sod better than the ordinary corrugator. The home-made implement shown in Fig. 47 has the advantage that it is not easily clogged with trash, the front portion of the runner pushing aside all material likely to catch on the cutting shoe. Several kinds of corrugators are used, but it will be found that those of the sled type give better results than those mounted on wheels or rollers.

The corrugation must be kept open if it is expected to spread water uniformly over a field; if it becomes clogged or damaged so

that it will no longer confine the irrigating stream within its banks, the process of irrigation becomes slower and less certain. Such deterioration is caused principally by the use of implements for crop harvesting and the best practice is to recorrugate following each harvest. In the case of pastured fields seeded to grasses, corrugations need cleaning out less often than when wagons and other machinery are drawn over them, but they should not be neglected entirely.

One man with the proper corrugating implement drawn by four horses can corrugate about 12 acres of land a day.

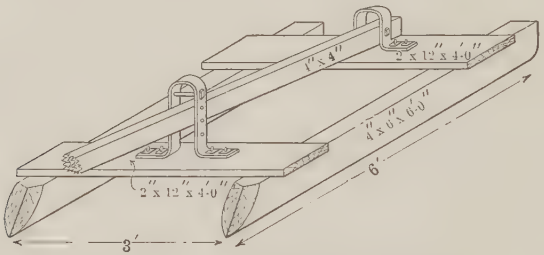


FIG. 47.—Furrower designed by Don H. Bark.

21. Border Method of Irrigation.—The essential features of this method consist in the division of the field to be irrigated into a series of strips by low, flat levees, or borders, extending usually in the direction of the steepest slope. Sufficient water is then turned into the upper end of each strip and this water moves down the slope in a thin sheet, moistening the soil to a given depth as it advances toward the lower end.

A smooth, regular land surface having a slope of 10 to 30 feet per mile is well adapted to the border method. Somewhat flatter slopes, as well as much steeper slopes, are used with fairly satisfactory results, providing the head of water is regulated to suit the slope and other conditions. A large volume of water may be required on flat slopes but cannot be handled successfully on steep slopes. In narrow, short strips the head used may be reduced to one-half of a second foot and in wide long strips 10 second-feet may be none too large.

The most favorable soil for borders is a free working loam, several feet deep underlain by a more or less impervious subsoil. As the sheet of water flows down each strip, the pervious top soil

is readily moistened and the less pervious soil beneath prevents or lessens the waste of water by deep percolation. Borders are also quite generally used where the subsoil as well as the surface soil is porous, not because such formations are the most favorable but because no other method will do as well.

A contour survey of the field or farm is, in most cases, necessary in order to locate the farm ditches and determine the width, length and direction of the borders. Such a survey should include soil borings to ascertain the character and depth of the

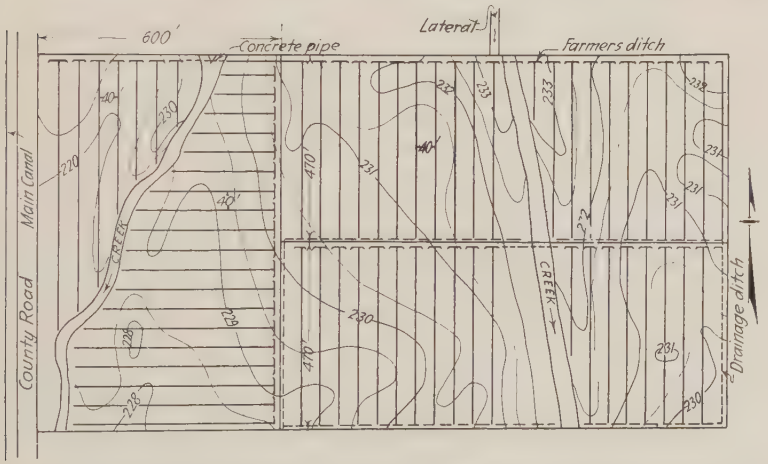


FIG. 48.—A farm in the Sacramento Valley, California, irrigated by the border method.

soil and subsoil, and the presence of hardpan or a water table. Figure 48 shows 1-foot contour lines, farm ditches and borders on one of the farms of the land settlement colony at Durham, Calif. It will be noted that the border strips are 40 feet wide and do not exceed 470 feet in length.

The width and the length of borders vary with the head of water available, the texture of the soil and subsoil, the slope of land, and to a less extent with the kind of crop grown and the amount of money available for such work. While the small-sized border tends to insure a more uniform moistening of the soil with the least waste of water, it necessitates the building and maintaining of more field ditches and structures and a larger

number of field levees, both of which are objectionable features from the farmer's standpoint. On the other hand, long borders in porous soils waste a large amount of water by deep percolation and are likely to show an uneven distribution of moisture in the upper layer of soil.

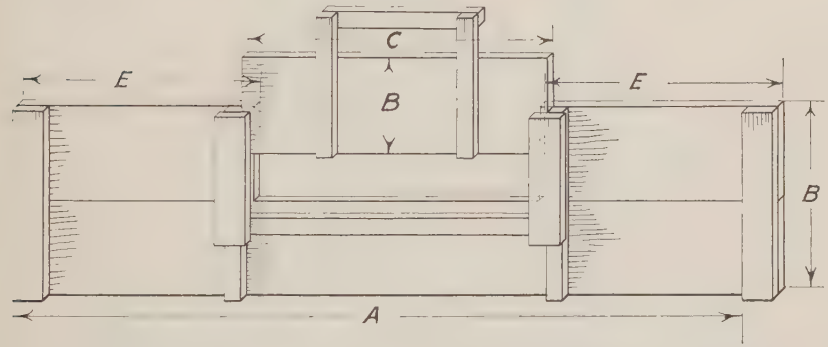
The field to be prepared for border irrigation is first plowed or disked. In case the soil is too dry and hard to allow this to be done successfully, it is watered as well as its nature will permit. Occasionally the ground is first levelled in a rough way by teams, or tractors and afterwards divided into strips and borders. The location of the border levees is indicated by long stakes which may be made of half laths, and when these are set, a straight plow furrow is run between stakes to mark in a more definite way the location of each border. A foundation for a border may be made by plowing two or three furrows on each side of the staked line, throwing the dirt toward the center. For small tracts the levees are built usually by the use of three-horse and four-horse Fresno scrapers, which are driven back and forth at right angles to the levee lines. As the earth is scraped from the high spots it is carried forward and dumped on each levee in passing. The amount of earth dumped on each levee depends on how far the scraper loads are overlapped. If large levees are required, two or more scraperfuls of earth may be dumped in the same place, but in small, low borders a slight overlapping of the loads may suffice.

The border levees, when first made, are composed of loose earth and are irregular in shape. To remedy the latter defect, several home-made implements have been devised. One of these is a wooden drag, trapezoidal in shape, drawn with the large end ahead. A common two-section drag-harrow may also be used to advantage. A hinge should be placed in the middle of the evener bar, to allow the harrow to lap down over the sides of the levee as it is drawn lengthwise of the border.

After the levees are built the space between each pair is carefully leveled and graded. In properly prepared fields the standard requirement for this part of the work is that the surface shall be practically level crosswise between borders, the greatest variation in elevation permissible being about one-tenth of a foot. Such close attention to grading is necessary in order that

the water may flow down the strip in a thin sheet of uniform depth. Otherwise it is certain to seek the lowest levels and may leave the higher spots unwatered or only partially watered.

The most common structures in border irrigation are the headgates to control the water entering each division or strip. These are made of lumber or concrete or a combination of the two. They may also be metal gates inserted in pipes. As in the case of supply or head ditches, the capacity of the head gates varies from 1 to over 10 second-feet, and it is customary to



Designed for Heads	A	B	C	D	E	Lumber Thickness
1 cfs – 2 cfs	8'-00"	2'-0"	3'-3"	1'-0"	2'-6"	1"
2 cfs – 5 cfs	9'-00"	3'-6"	3'-3"	2'-0"	3'-0"	1½"
5 cfs – 8 cfs.	10'-00"	3'-6"	4'-3"	2'-0"	3'-0"	1½"

FIG. 49.—Standard single-wing wooden head gate.

design each of such a size that it can transmit the entire flow of the head ditch or pipe. Figure 49 shows a standard single-wing head gate of wood, which may be built in three different sizes, from 1 to 8 second-feet capacity, as outlined in the table of dimensions.

Because of the short life of untreated lumber when in contact with earth, border head gates built of concrete are being used by farmers under a number of canal systems. Sketches of such gates are shown in Figs. 50 and 25.

When water is conveyed to borders through pipes, it is distributed to the head of each strip through short stands resting on

the top of the feed pipe or on the top of short branch lines. In case concrete pipe is used, the valve which controls the water is inserted in the top of the concrete stand as indicated in Fig. 51. To reduce the number of valves and thereby lessen the cost, one

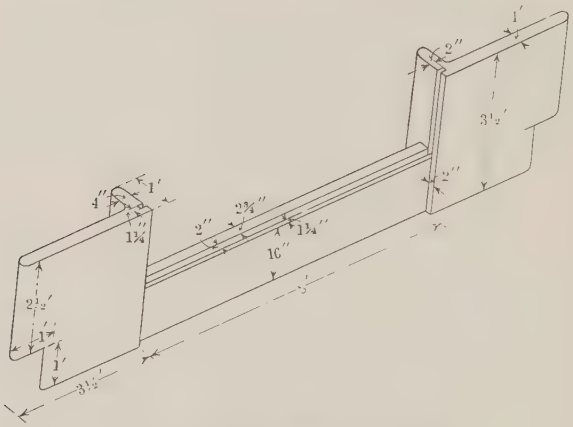


Fig. 50.—Border gate of concrete.

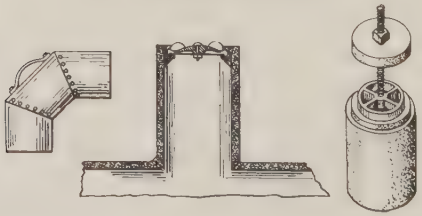


Fig. 51.—Metal valve inserted in concrete stand, and portable hood.

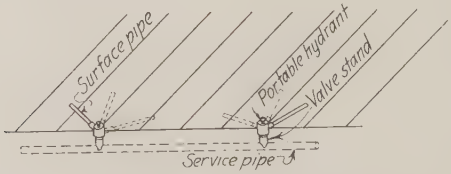


Fig. 52.—Method of flooding field in border method of irrigation.

valve may feed several strips in turn by means of a portable hydrant which is fastened to the stand and the requisite number of joints of galvanized steel surface pipe. A section of the portable hydrant having a connection for the surface pipe and

the manner in which several strips may be watered from one valve are shown in Fig. 52. A similar valve attached to a steel riveted pipe is shown in Fig. 53.

In preparing land for border irrigation, practice differs in various parts of the West. Thus in the Southwest, two extremes as regards the size of border strips are found. In the Salt River Valley in Arizona the common width of the strip is 50 feet and

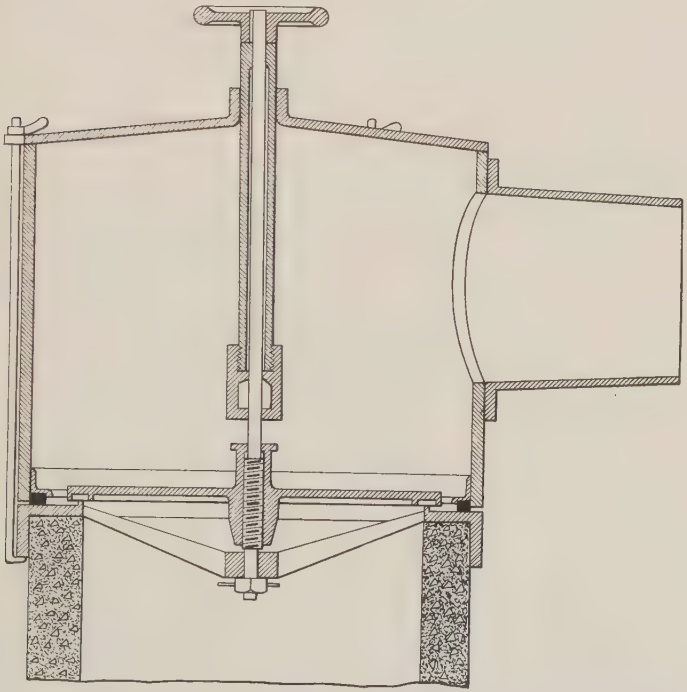


FIG. 53.—Portable hydrant attached to valve shown in Figs. 51 and 52.

the length a quarter of a mile. This is good practice where the heads are large and porous soils overlie tight subsoils, but where the subsoil is porous the run is much too long. Figure 54 shows a bordering implement used in the Salt River Valley, Ariz.

In southwestern Texas the largest areas enclosed between borders seldom exceed 25 feet in width and 330 feet in length. These are used for alfalfa and grain and those made for truck crops are smaller. The levees and heads of water used are

smaller, the minimum flow being about half a second-foot, and the maximum less than 5 second-feet.

In the light sandy soils of the Columbia River basin, the border method has proved to be the most efficient. Here the borders are short and narrow, the average length being 200 feet and the width ranging from 20 to 40 feet.

In California many of the big ranches which have been dry-farmed for 60 years or more are being provided with a water supply, subdivided and prepared for irrigation. In fitting the surface for irrigation, the border method is extensively used.

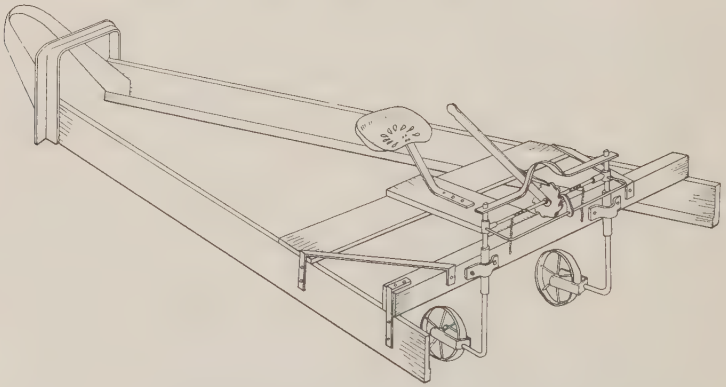


FIG. 54.—Bordering machine used in Salt River Valley, Arizona.

This work is done for the most part on a large scale and large implements operated by tractors have taken the place of the horse team and scraper, as used on the small farm.[1]

22. Flooding from Field Laterals.—This is sometimes called the Rocky Mountain method of irrigation since it is in general use in the states of Colorado, Wyoming, Montana, and Utah and is more or less practiced in other western states. To state that 40 per cent. of all the land irrigated west of the Missouri River is irrigated in this way is not far from correct. Apart from the labor involved in spreading the water, its efficiency compares favorably with other methods and its cheapness commends it to settlers of small means. Besides, it is well adapted to such soil

[1] For a more complete description of this method consult *Farmers' Bull.* 1243, *U. S. Dept. of Agr.*, on "The Border Method of Irrigation," by SAMUEL FORTIER.

and topographic conditions as prevail in many of the mountain states where the land is often rolling and the most fertile soil shallow. Its use may be recommended on rolling land where the most fertile soil is found in the first foot, where the land and water are reasonably cheap, where the water is delivered in heads of 1 1/2 to 3 second-feet or more, where grain follows fodder crops in rotation and where little or no hired help is employed to do the irrigating.

A contour survey is a valuable aid in applying this method to new land. If no such survey has been made, the feed ditches and laterals should be roughly located by means of a surveyor's level and rod.

The field laterals may be made with a common walking plow, but a lister or double mould board plow attached to a sulky frame is to be preferred for medium-sized ditches or laterals. The larger laterals, designed to carry 3 to 4 second-feet, may be made by bolting together two steel team plows. Laying out laterals may be done either before or after seeding. It is essential, however, that the field be leveled and graded preferably after the ditches have been built in order that water may flow to a uniform depth over the space between laterals.

The grade of laterals varies from 1/2 to 1 inch to the rod and they are spaced about 75 feet for grain and about 90 feet for fodder crops. The latter being perennial crops, the field ditches are built with more care.

The direction of the laterals may be (1) along curved graded lines, as shown in Fig. 55; (2) down the steepest slope, as in Fig. 56; or (3) diagonally down the slope.

In the first, the laterals are built approximately along contours and are given just enough slope to produce the desired velocity of flow. Irrigation is accomplished by turning the water out at intervals along the lateral and allowing it to flow down the slope to the next lower lateral. This method is usually employed on very steep slopes.

In the second, the laterals are built directly down the slope, the grade of the lateral approximating that of the slope, and usually no attempt is made to reduce the velocity of the water. The water is turned out at intervals along the lateral and the flooding is accomplished by the water flowing simultaneously laterally

and down the slope. This method can not be employed on very steep slopes as the water will have a tendency to follow alongside the lateral and produce serious washing of the soil and will not spread out laterally to any appreciable extent.

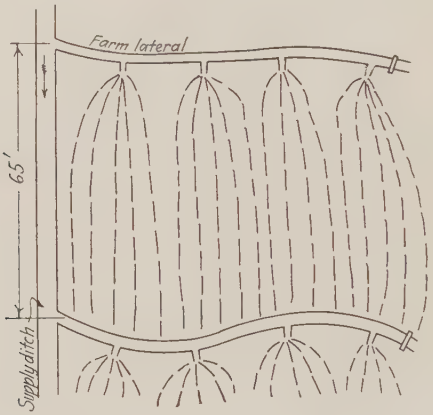


FIG. 55.—Flooding from field laterals.

In the third, the laterals built diagonally down the slope have a tendency to approach a mean between the two methods mentioned above. Such a lateral has a steeper grade than that of

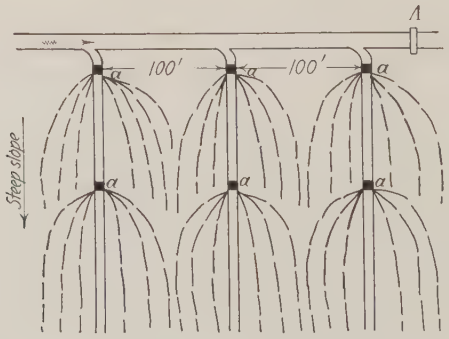


FIG. 56.—Flooding from ditches running down steepest slope.

the contour lateral and a lighter grade than that of the second method; thus the velocity of the water in the lateral is increased over that in the first and decreased under that of the second case.

With this method water can be run a slightly greater distance than by either of the first two methods mentioned, before it must be changed.

There are two distinct methods employed in irrigation by flooding, each of which has its advantages and disadvantages. One method is to begin to irrigate with the lowest lateral and work up the hill. The advantage of this method is that there is always dry land upon which the irrigator can cross from one part of the

FIG. 57.—An alfalfa field near Berthoud, Colo., showing supply lateral, field laterals, contours, and waste ditches.

field to another. The disadvantage is that all waste water recovered by a lower lateral must be turned upon land that has already been irrigated. The other method is to begin with the upper lateral and work down the slope. This method has the advantage that all waste water can be collected in a lower lateral and turned upon land that has yet to be irrigated. The disadvantage is that the irrigator has more or less wet ground where he is at work changing the water.

A somewhat different arrangement of field laterals is shown in Fig. 57 and is a common practice on the undulating lands of Colorado where the most emphatic advice given by the experi-

enced irrigators is "See that your laterals are laid out to the best advantage at the outset and that your fields are thoroughly graded." The old adage that "work once well done is twice done" can be applied to preparing fields for irrigation.

In laying out a system of laterals for a new farm it is important that the supply ditch commands the greatest extent of irrigable land. It may take years to convert all the raw land into irrigated fields but the ditches should be so designed and located as to serve this purpose at the proper time. The mistake made by so many new settlers is to run water to a part of each farm and to install a system of irrigation for this part without regard to the irrigation of the balance. As the irrigated area is enlarged the irrigation layout is found to be inadequate and faulty, and money and labor have to be expended in correcting the error, the result being unsatisfactory in the end.

23. Check Method of Irrigation.—Flooding crops in checks or compartments has been practiced in various forms from the earliest antiquity. It is still a common method of applying water in many of the irrigated regions of Asia, Africa and Europe, and was introduced into western United States by the Spaniards, Mexicans and Mexican Indians. On the banks of the Rio Grande in New Mexico and elsewhere in the Southwest, one still sees crops of grain, alfalfa and vegetables grown and irrigated in small, rectangular check beds. The small areas inclosed and the low banks which form the boundaries closely resemble the basins in irrigated orchards. There may be from 10 to 50 check beds on a single acre, and the manner of flooding the check beds is much the same as that described under the "Basin Method."

Californians, in adopting this foreign mode of irrigation, introduced many changes to adapt it to American ways of farming. Strong teams, heavy plows, and large scrapers were substituted for the hoe, spade and mattock of the Mexicans. The owners of these farms and outfits had also large ideas of how land should be prepared for irrigation. In their opinion the small check bed, 20 by 40 feet, surrounded by a 10-inch bank, might do very well to water Mexican chili, but alfalfa fields, farmed on a big scale, required to be prepared in a wholly different manner. These men, accordingly, went from one extreme to the other. From

checks containing the one-twentieth of an acre they increased the size to 10, 20, and 30 acres in each check. These large checks have proved failures from the start. The farmers who adopted this style years ago have had no end of trouble in lowering the levees and reducing the size of the checks.

The modern method in this country consists in dividing the field, or tract, to be irrigated into a number of small compartments averaging about three quarters of an acre in extent and surrounding each by a low levee. Provision is made to flood each compartment, or check, by means of a gate or box placed in the ditch bank.

While this method is not as popular as it was 15 years ago, the "border method" having taken its place under many systems, it can be used to good advantage when conditions are favorable. It is well adapted to flat lands where the slope may vary from 1 to 10 feet per mile and where water is delivered in heads of 5 to 20 second-feet. It is economical of water in light sandy soils, the surface of an ordinary check being flooded to a depth of 6 inches with a head of 10 second-feet in less than 30 minutes. It also assures the penetration of the volume of water applied less the amount evaporated in heavy clay soils.

There are various modifications of the check system in use. When the levees follow the natural contour of the ground surface, the enclosed spaces are called contour checks. Figure 58 shows a 40-acre field prepared by the contour method in which the single lines represent the levees built on the contours and the double lines, the field ditches. Cross levees are constructed to break up some of the larger checks, making the average size of each compartment 1 acre or less in extent.

Before the checks can be formed, it is necessary to make a survey to determine the location of the levee lines and the field ditches. Engineers follow somewhat different methods of conducting a survey of this kind but the general operation and the end attained are the same. A party of three consisting of a levelman, rodman and a man following with a plow can work to advantage. The levelman sets up his instrument where he can command a good view of the field and takes a number of random readings at different points to gain a general knowledge of the topography. He then selects a point on the highest contour and

takes a reading on a hub or stake driven flush with the ground. This stake may be referenced, to be used as a bench-mark for future surveys. The levelman after noting the rod reading calls this the grade rod and locates points of the same elevation by having the rodman proceed over the field with the target set at the initial reading. The rodman marks each point with a stake and the plowman follows closely behind connecting up each point with a furrow which marks the location of the levees. When the rodman has reached the end of the field, he moves the target up the correct distance from the contour interval decided upon and starts across the field a second time, locating the new contour

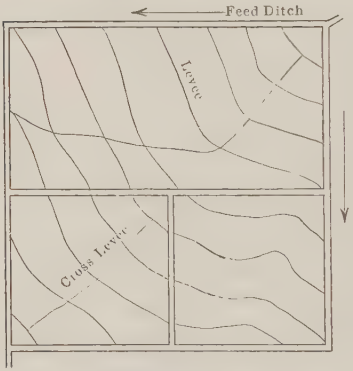


FIG. 58.—Forty-acre field showing contour checks.

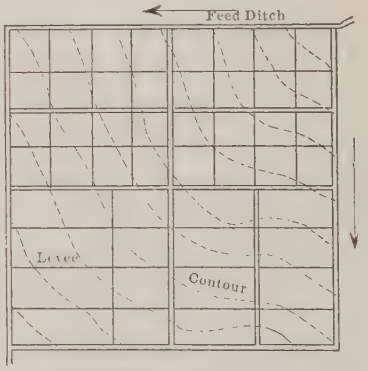


FIG. 59.—Rectangular checks on field shown in Fig. 58.

line, the plowman following as before. Three or four inches is the usual vertical distance between contours and it will not be found advisable to contour land that slopes more than 2 feet in 100 feet. The height of the levees depends upon the difference in elevation of the contour lines and the depth of water applied in one irrigation. As a rule levees 8 or 9 inches high after being settled and with a base of 6 to 8 feet will be found satisfactory. These offer but little difficulty in cutting and harvesting crops, while high levees are often troublesome in this respect.

Rectangular checks are often preferred to the contour type. Figure 59 shows the same field as that sketched in Fig. 58 prepared by building the levees in straight lines thus forming a series of rectangles. In either case the levees are generally made by

scrapers drawn by two or four horses. The soil from the high parts within the checks is removed to the lower spots or dumped along the levees. The proper leveling of each check is important. The size of the checks depends largely upon the slope of the land, the character of the soil and the head of water available.

24. Basin Method of Irrigation.—This method as practiced in the United States should not be confused with that in use in upper Egypt, where the basins average 7,000 acres in area and are surrounded by embankments or dykes 12 feet high. In this

FIG. 60.—Ridging machine made by John Deere Co.

country the basin method is essentially the check method adapted to orchard irrigation. Ridges of loose earth are thrown up midway between the rows of trees in two directions at right angles to each other. These form a large number of square basins, or enclosures, with one tree or several trees in each. The ridges are made with a special implement known as a "ridger." There are various forms of home-made ridgers in use, which are drawn by teams. In recent years tracters have taken place of teams in the larger orchards and the ridging is done by manufactured implements one of which, made by the John Deere Company, is shown in Fig. 60.

Interest in basin irrigation has been renewed of late in California owing to the fact that by this method of preparing land and applying water it has been found possible to mulch each basin throughout the dry season with cured alfalfa, bean straw or other leguminous product. The soluble ingredients of such a mulch are carried by the irrigation water into the soil and in this way both food and moisture are furnished to the tree. The objection to this practice is that mice and insects lodge in the mulch and attack the trees. This is a revival of a very old practice. Ibn el Awam, or Abu Zacaria, as he is called otherwise, who wrote in the twelfth century, speaks many times of mulches of straw, preferably bean stalks, in his book on agriculture.[1] The same author in another part of his work gives the following advice:

> You next take bean stalks with the beans stripped off, coming from the crop of the previous year and quite large. They are thrashed so as to reduce them to the state of very fine straw. This straw is spread in abundance on the soil after plowing and you irrigate on top of it.

Guillochan[2] says that it is excellent orchard practice after rotted manure has been spaded in early in the spring and the basins (cuvettes) have been formed for receiving irrigation to fill the latter with straw manure or, if this is not to be had, with dry grass.

There are several methods of flooding basins practised. One of the most common and perhaps the best method is shown in Figs. 61 and 62. Double ridges are made between alternate rows of trees, forming a small ditch through which water is conveyed from the head ditch in the direction of the greatest slope. The basins are flooded in pairs beginning with the lowest tier. Another method of flooding basins is to let the water from the feed ditch take a zigzag course through the basins by making openings in opposite corners of each compartment. The principal objection to this method is that the basins nearest the head ditch receive the most water. To prevent water coming in contact with the trunks of the trees, which is considered detri-

[1] "Kitab al-Felahah," translated into Spanish by José Bangueri, Madrid, 1802, and into French by J. H. Clement-Mullet, Paris, 1864–1866.

[2] "Traité paratique d'horticulture pour le Nord d'Afrique," p. 185. Paris, 1907.

mental by some orchardists, ridges may be formed between the rows of trees. These form small basins around each tree, the

FIG. 61.—Basin method of irrigation.

water being applied to the outer basin. Ordinarily the orchard can be graded leaving a small mound around each tree high enough never to be submerged.

FIG. 62.—Basin irrigation of orchards.

After each irrigation the ridges are worked down to the general ground level and the orchard is thoroughly cultivated and harrowed.

The main advantage of this method is the assurance which it offers of a uniform wetting of the soil over the entire root-zone of each tree.

25. Surface Pipe Method of Irrigation.—This method is an outgrowth of irrigation by pumping. It requires no ditches, check or border levees, nor is it essential that the surface be graded to a uniform slope. For these reasons it is rapidly gaining in favor in the East and is destined to become one of the most common methods of applying water under humid conditions. When irrigation is practised to supplement the natural rainfall during dry spells, relatively small quantities are needed. An application of 2 acre-inches per acre is usually sufficient at any one time. Accordingly, pipe mains ranging in size from 6 to 12 inches in diameter convey sufficient pumped water to the highest portions of the fields from which it is distributed through movable surface pipes attached to special hydrants or stands on the head mains. All main and head pipes are laid far enough below the surface not to interfere with the plow or subsoiler. When a field has been watered and the surface pipes removed, nothing remains to interfere with the ordinary processes of growing and harvesting crops until a second watering is needed. To be free from the inconvenience of an open ditch, levee or other field obstruction, and to be able to utilize the space which these occupy, are strong incentives to adopt this method. It is also well adapted to the irrigation of the rolling and irregular land surfaces of the Atlantic Coast states. As will be noted later the surface of fields should be carefully graded and smoothed as a necessary preparation, but only to a limited extent can this be done in the far East where the soil is too shallow to permit much surface grading.

This method is used occasionally for the irrigation of alfalfa in southern California and for the irrigation of orchards in other parts of that state. The concrete head pipes for alfalfa are usually 12 inches in diameter are laid beneath the surface. About 100 feet apart, stands of the same material are inserted in the head pipe and at the top of each stand a valve is placed as shown in Fig. 63.

Standpipes which project a foot or two above the surface are seldom used in irrigating alfalfa. The more usual practice is to

use only a portion of a joint of pipe for stands which terminate 4 to 6 inches below the ground surface. When the valve is protected by a covering of earth when not in use, wagons and other implements can pass over it without injuring it.

The detachable surface pipe is made of galvanized iron, usually 24 gage. It is 8 inches in diameter and is made up in 10-foot lengths. Each length consists of a single sheet of metal which is

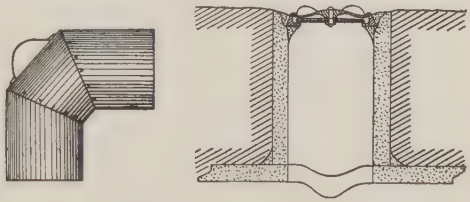


FIG. 63.—Stand and valve for irrigating alfalfa.

rolled, crimped and soldered in the manner shown in Fig. 64. The socket end of each length is reinforced by a ring and the spigot end is formed by riveting a tapering joint 8 inches long of 20 gage.

With a head of 60 miner's inches (1 1/5 second-feet) one man can irrigate 2 1/2 acres in a 10-hour day. In irrigating a field the water is used from one stand for a strip equal in width to the

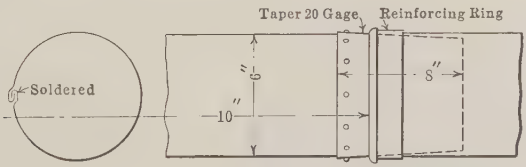


FIG. 64.—Surface pipe for irrigating from stands.

distance between stands and in length from the head to the foot of the field. If one begins to irrigate at the upper end, he proceeds toward the lower end by gradually adding sections of pipe until the entire strip is watered.

Where the depth and fertility of the soil and other conditions will permit, it pays to grade alfalfa fields with as much care for this method as for any other. If the surface is left rough and uneven the water can not be evenly distributed, causing dry spots

on the high places and over-irrigation and scalding in the low places.

26. Subirrigation Method.—Crops are said to be subirrigated when the irrigation water is supplied from beneath the surface and is drawn to the roots by the force of capillarity. The water used in subirrigation may be supplied in two general ways: first, through some form of artificial conduit, such as tile or cement pipe, and second, by raising the natural water table high enough so that the plants can draw upon it for their growth. The first may be termed artificial subirrigation and the second natural subirrigation. In either case at least three conditions must exist in order to make subirrigation practicable: namely, a porous surface soil which allows rapid movement of the moisture laterally or upward; an impervious substratum; and drainage facilities to prevent the complete waterlogging of the land. There are few localities where these three conditions exist simultaneously and the area of land adapted to subirrigation is therefore very restricted.

Artificial Subirrigation.—To the uninitiated this has always seemed an ideal method of wetting soil. Theoretically regarded, it is supposed to prevent the wetting of the top soil and thus lessen evaporation losses. There is no waste from surface run-off, the water can be easily controlled and the cost of application is low. As a rule, these theoretical conclusions are not borne out in practice. A large number of subirrigation plants were installed in western Kansas and western Nebraska from 1910 to 1917 and the promoters claimed for this method the following advantages: (1) It requires less water than for surface irrigation; (2) the temperature of the soil is warmer; (3) the amount of evaporation from the soil is less; (4) there is no erosion of the soil; and (5) greater and better crop yields are obtained. These plants to the number of 59 were examined by H. C. Diesem[1] for the U. S. Department of Agriculture, in 1917, and he found among other things that of these 24 had been abandoned, 24 were being operated and 11 were being partially operated. With a few exceptions these plants consisted of a small pumping plant and porous concrete conduits with nozzles spaced about 4 feet apart. A porous nozzle is shown in Fig. 65.

[1] Diesem, H. C., "Subirrigation in a Portion of the Great Plains Area."

A common diameter of the conduit was one and three-fourths inches, which was occasionally increased to 2 inches but rarely to 3 inches. These conduits were laid at depths of 12 to 24 inches

FIG. 65.—Cement pipe for subirrigation, showing porous nozzle.

and spaced all the way from 4 feet to 30 feet and more apart. The conduits when well made and laid were altogether too small to convey the requisite quantity of water for the crops grown, and to make matters worse the nozzles frequently projected into the pipe, as shown in Fig. 66.

FIG. 66.—An improperly inserted nozzle.

Some of the conclusions reached by Diesem are: That the soil and subsoil as well as the crop to be grown are determining factors in fixing the depth, distance apart and capacity of the conduits; that the economical spacing of conduits for any tract can only be determined by experiment but seldom exceeds 8 feet; that surface methods of irrigation are more economical of water than subirrigation; and that it costs from $200 to $300 an acre to install such systems as he investigated in Kansas and Nebraska.

In 1913, on the Higley experiment farm near Mesa, Ariz., a number of lines of concrete pipe 4 inches in diameter and made similar to the subirrigation conduits described were laid 16 inches deep and 17 feet apart for the irrigation of cotton. One row of cotton was planted directly over each pipe line and three rows between every two spaced, respectively, 4 feet 3 inches and 8 feet 6 inches. On May 9, the seed was planted and an irrigation equivalent to 8 inches over the surface was applied at the rate of 240 gallons per minute. The seed planted directly over the pipe lines germinated quickly and grew vigorously throughout the season; the rows 4 feet 3 inches distant responded in places with quick germination and strong growth but in others the germination was slow and the growth weak. Five-eighths of the seed planted in these rows failed to germinate. In the middle rows, 8 feet 6 inches distant from the pipe line, not a single seed germinated and the moisture content of the top 18 inches of soil which averaged 6.5 per cent before irrigation steadily decreased to 3.5 per cent.

The above confirms what the author saw in 1910 on a subirrigated tract of 6 acres planted to alfalfa near Garden City, Kan. The crop was growing fairly well for a distance of about 3 feet on each side of each pipe line but the intervening space evidently received no water since the yield did not exceed that of the dry farms.

Perhaps the most successful subirrigation is to be found in the vicinity of Sanford, Fla. The district is known as the Palmetto Flatwoods, which have a smooth surface and a slight fall to a lake. The soil is sandy and is underlaid by hardpan, which is a decided advantage from the standpoint of subirrigation since it forms a bottom for the moisture reservoir, thus holding the water close to the plant roots and assisting greatly its lateral spread. Water is turned into the irrigation systems from flowing wells and allowed to run until the whole soil area is saturated to the surface. Then the tile drains are opened and the excess is allowed to drain off. This is done at times of setting out young plants rather than during the growth of the crop.

As the larger part of the land is naturally too wet for cultivation and must be drained as well as irrigated, the system of tiling used is designed to answer both purposes. The tile system consists of a water-tight main pipe feeding a series of open-jointed

parallel laterals placed 16 to 18 inches deep. The mains are laid parallel to the surface regardless of grades and are located on the highest side or on the ridges throughout the field so that the laterals slope away from the mains at the proper depth. The mains are 4- to 5-inch vitrified terra cotta pipe which is obtained in 2 1/2-foot lengths with bell ends. The joints are made water tight with cement. A stop-box is placed at the intersection of each lateral with the main. Holes are cut in the side of the pipe and a short length of 2-inch steel pipe is cemented into place to form a connection between the main and the head stop-box, the lateral leading out from the stop-box. This metal pipe also forms a neck in which wooden plugs or other devices may be inserted to control the flow of water.

The laterals are built of 3-inch clay drain tile which are obtained in 12-inch lengths. The pipe are laid with open joints by placing the short lengths end to end. A shovelful of sawdust or cinders is placed over each joint to prevent fine sand from working into the line and stopping up the pipe. The grades for the lateral trenches vary from 1/2 inch to 3 inches per 100 feet and the laterals are spaced 18 to 24 feet apart, the shorter distance being preferable.

The cost of this system ranges from $100 to $125 per acre, not including the water supply or the drainage outlet from the field.

The first irrigation usually is applied when the first winter crops are planted in the fall. Later irrigations occur at intervals of 10 days to 2 weeks thereafter during the growing period. The length of time required to saturate the Sanford soils varies from 2 or 3 hours to 24 hours, depending on the amount of water in the soil prior to irrigation, the depth to hardpan and the texture of the soil.

Subirrigation from open ditches is also practiced in Florida, this method being adapted to very level land and for shallow-rooted crops. It is necessary to drain this land during the summer season and to irrigate it during the winter. The drainage is done through surface ditches cut 3 to 5 feet deep. The fields are drained into the border ditches by surface laterals which are also used as irrigation laterals.

The land is prepared for irrigation and drainage by throwing the soil into ridges 12 to 13 inches high and 4 feet apart. Irri-

gation laterals are placed at intervals of 40 feet running in the direction of the rows. Grades are very flat and the water is held in the ditches by earthen dams until the moisture shows on the surface over the entire area between ditches.

Natural Subirrigation.—Frequently the seepage water from porous, earthen ditches and the waste water from irrigated areas pass through the subsoil of lower fields sufficiently near the surface to subirrigate them. In other places these seepage waters collect at the lower levels and raise the ground water near enough to the surface to supply the plants with the needed moisture.

Perhaps the most notable subirrigated area in the arid region is found in the vicinity of the towns of St. Anthony and Sugar City in the upper Snake River Valley, Idaho. This subirrigated district comprises an area of about 60,000 acres. The surface soils in this area are gravelly or clay loam, varying in depth from 1 1/2 to 6 feet. The land slopes at the rate of about 10 feet per mile. An impervious lava rock is found at a depth varying from a few feet to 90 feet. This land was at first irrigated by the usual methods, but, owing to the porous nature of the soil, the water rapidly sank to the bed rock and it was not possible to retain sufficient moisture in the surface soil to insure good crops. In time, however, the subsoil filled with water and the top soil began to receive moisture from below. This led to a new method of irrigation. The water is supplied to the fields in shallow ditches 3 feet wide, 6 inches deep and not to exceed 1,320 feet long. These ditches divide the farm into strips 100 to 300 feet wide. By this method no water is spread over the surface, the laterals merely distributing from 15 to 20 miner's inches to different parts of the field where it soon joins the ground water by sinking through the bottoms of the shallow ditches. The water is kept running continuously until the water table rises high enough to supply the needed moisture to the roots of the plants. Thereafter the ground water is regulated by the amount of water turned into the supply ditches. The rise and fall of the ground water is determined by means of small boxes set in the ground 3 to 5 feet deep. From 20 to 30 boxes are usually required for each 80-acre farm.

A system of subirrigation very similar to that just described is practised in parts of the San Luis Valley, Colorado. The best

results are obtained on porous sandy loam soils underlaid at a depth of several feet by an impervious stratum and on land having a slope of 5 to 10 feet per mile. Most of the land in the valley is of uniform slope and the custom is to run the ditches parallel to the section lines in the direction having the least slope. They are spaced at intervals varying from 50 to 250 feet according to the character of the soil, the depth to the normal water table and the amount of irrigation in the neighborhood affecting the water table.

There are many modifications of the above method in the San Luis Valley. Where the soil is thin or leveling is impracticable for any reason, the field ditches are carried along the ridges. In the river bottoms, sloughs or old channels are dammed and kept full of water during the season. In other cases small reservoirs have been built to catch excess water which is allowed to seep out and saturate the subsoil.

27. Flooding Wild-grass Meadows.—More than a million acres of wild-grass lands are irrigated in this country. Compared with other irrigated lands, the wild-grass meadows have a low value, the average yield is less than a ton per acre of cured hay and the average annual returns are from $10 to $20 per acre. The irrigation of this crop forms a transition stage between the non-irrigated grazing meadow and the more highly developed irrigated farm. No standard methods have been devised for the wetting of the soil; the surface of the ground is unprepared for water, it being injurious to disturb the native sod; and it represents, in short, the crudest efforts in the artificial watering of land. It provides, however, a means of supplying fodder to stock during periods when range feed is not to be had and although the yields are small the interest on the investment and the cost of applying water are also small, making the net returns reasonably profitable. As stated there is no standard method of irrigating wild grasses and pastures since the manner of flooding followed depends on the water supply, slope and configuration of the land, kind of wild grasses grown and other conditions. The object is to make use of large quantities of flood waters by spreading them over river or lake bottoms by the cheapest possible means. A stream, in traversing a flat valley, meanders in its course and numerous channels and swales are formed by a long-continued succession of floods. The Humboldt River as it

meanders during average high water through a wild-grass meadow near Battle Creek, Nev., is shown in Fig. 67. The stockman takes advantage of these natural water courses and by placing in each, at suitable points, dams of loose rock and brush or other material manages to divert water to lands that would not be inundated otherwise. In other cases, the loose rock dam is placed in the main channel of the stream, the object being to raise the surface of the stream to such a height that it will overflow its banks and submerge adjacent lands. The flood

FIG. 67.—Humbolt River, Nevada, with average high water in May.

waters passing over these dams tend to replace part of the loose rock by washing out the stones along the crest and rolling them down stream until they find a lodgment below the toe of the structure. With each year's repairs however, they become stable in time and permit the floods to pass over them without injury. In still other cases inexpensive canals are dug to carry flood waters to meadows, and other channels are provided to drain them to prevent injury to the grasses and permit the crop to be harvested.

The flow in such canals is not controlled in any way other than by making openings in the lower bank at suitable places and

allowing the water to inundate the lower lands by wild flooding. The surface being uneven, in its, natural state it may be covered to depths of a few inches or several feet depending on its elevation. In some localities the meadows are flooded but once during high water but in others where the water is under better control they may be flooded two or more times. In all cases it is desirable to keep the water moving in flooding meadows. When the native plants are submerged for too long a time in stagnant water, the more nutritious, such as blue joint, red top, sugar grass and wild clover, are likely to be injured, if not destroyed and their place taken by worthless plants such as tules, cat tails and wire grass.

Some contend that the lands which are now held in large holdings and irrigated by wild flooding methods for the production of native hay and pasturage should be subdivided, the native sod broken up, the land properly prepared for irrigation, tame grasses and other crops seeded and an ample water supply provided during all of the crop-growing season. They claim that if the improvements outlined were made the crop yields would be trebled and the present value of the land increased proportionately. This will be done eventually but it is thought that the proper time has not come to make the change. So long as there are several million acres of arable land provided with water rights in the West that are unsettled it would seem wise to permit the stockmen to practise wild flooding since, in 1919, the value of the hay harvested from such lands amounted to nearly $18,000,000.

28. The Irrigation of Pastures.—Stock are usually grazed on land that cannot be cultivated. Sometimes it is a marsh but more commonly it is a rocky hillside that produces native plants on which domestic animals feed. These feeding grounds, however, may be at considerable distances from the homestead and it is desirable in many cases to have pastures near home. This is especially true of diversified farming in which the keeping of cows and hogs forms part of the work of the farm. If cows are to be grazed on irrigated pastures the field should be divided into two nearly equal parts in order that one part may be irrigated and the top soil permitted to dry out before the stock from the other part is allowed entrance. This rule applies to horses, sheep and other stock.

The kind of grass seed to sow on irrigated pastures will depend somewhat on the climate, soil and kind of stock fed. Well-established alfalfa is used for hogs, but cows thrive best on mixed grasses. For dairy cow pastures, Hansen[1] recommends the following mixtures for southern Montana conditions:

Pasture Mixture	Seed per Acre, Pounds
Smooth brome grass	3 to 4
Kentucky blue grass	4 to 6
Orchard grass	4 to 6
Meadow fescue	3 to 4
White clover	1 to 2
Alsike clover	1 to 2
Total	16 to 24

Seeding is done in the spring preferably without a nurse crop and the first season's crop is cut for hay although grazing may be permitted after August 15. Grasses are shallow rooted and require for rapid growth a moist top soil. Frequent light irrigations are accordingly necessary, the number in the season varying from five to eight. The average length of the grazing season under Hansen's experiments was 140 days and each acre supported on an average 1.78 cows which produced net returns in the form of milk, butterfat and skim milk of $52.06 per acre.

29. Irrigation of Peat Soils.—Peat soils contain a large percentage of decayed vegetable matter and this ingredient causes them to be light in weight, porous in texture and to shrink when passing from a wet to a dry state. An excess of organic matter and a deficiency in soluble mineral matter, more especially the salts of lime and potash, constitute their chief characteristics. Sometimes, however, in river deltas and elsewhere, the organic matter is mixed with the proper amount of alluvial earth and this combination makes a fertile and enduring soil. In other cases peaty soils are rendered partially or wholly unproductive by a lack of mineral ingredients.

The largest areas of peat lands are to be found under humid conditions but in the arid and semiarid regions of this country a considerable extent of peat land is to be found around the margin

[1] Hansen, Dan, "Irrigated Pastures," *Bull.* 166, *Mont. Exp. Station*, 1924.

of lakes, in flat river bottoms and at the estuaries of some of the largest water courses. As a rule these peat lands have not been reclaimed and in their natural state yield small returns in wild hay and pasturage. Their reclamation usually involves the control of the water table by drainage as well as irrigation, and the growing of crops adapted to this kind of soil. Owing to the first cost of drainage and irrigation in either combined or separate systems and the risk involved in growing and marketing special crops, farmers have been reluctant to spend money and effort on such ventures. The success, however, which some owners of peat lands in the West have had in growing marketable products would seem to be an incentive to others to make better use of their low producing peat soils. One of the best examples of successful peat-land production is to be found in the delta of the San Joaquin and Sacramento rivers in central California. This delta embraces a triangular area of about 570,000 acres composed of islands, sloughs and mainland. Many of the islands are below flood-flow levels and are protected by marginal levees with a ditch near the inner toe of the levee embankment to carry off the seepage water. Satisfactory crops of asparagus, potatoes, celery, onions, beans and other vegetables are grown. In 1924, 33,610 acres were planted to asparagus which yielded over 1,500,000 cases valued at $6,000,000.

By means of pumps, syphons and drainage ditches, some of which also serve as irrigation ditches, the soil water is properly controlled to meet the requirements of the plants grown. The pumps are used to remove drainage water in the rainy season and to provide an irrigation supply during the dry summer. The syphons made of pipes 8 to 14 inches in diameter are laid over the levees.

There are three kinds of ditches. One is the so-called 4-foot ditch which is 4 feet deep and 30 inches wide. In the sketch (Fig. 68) of King Island, one of these extends completely around the island at a distance of about 150 feet from the inside of the levee. Its function is to intercept seepage, but it also acts as a distributor. The same kind of ditch conveys water at frequent intervals from the syphons, at the levee, to the spud ditches. Spud ditches (Fig. 69) are about 10 inches wide and 16 inches deep and correspond to field laterals, being filled in and abandoned

at the end of each crop-growing period. They are spaced 60 to 100 feet apart and the water within them can be kept at the desired elevation by temporary checks made of shingles. The third

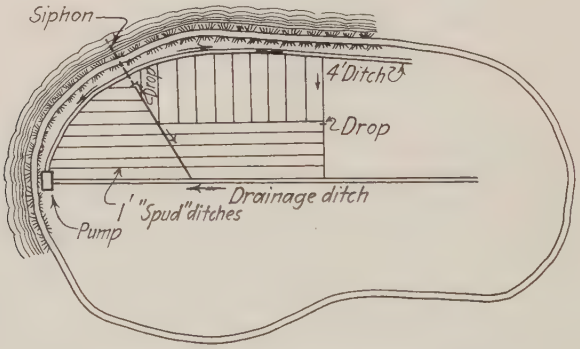


Fig. 68.—Typical irrigation layout on King's Island, California.

ditch is the drain usually extending across the middle of the island. The waste water from the 4-foot ditches discharges into this drain. In fact the lower ends of the 4-foot ditches also function as drains.

Fig. 69.—Trenching machine digging a "spud" ditch.

The kind of crops that can be raised on the delta lands of California depends to a large extent upon how effectively the water can be controlled. Where little control is practised, the land is

devoted to the growth of native grasses and the pasturing of stock. Where there is partial control, as in the case of tidal gates which admit irrigation water and discharge drainage water, cereals and forage crops may be raised, but where the soil water, irrigation supply and drainage water are under such effective control that the ground-water level can be either raised or lowered quickly, highly profitable yields of asparagus, potatoes, onions, beans and other crops can be obtained in rotation periods.

39. Spray Irrigation.—In spray irrigation water is applied to the surface of soils and crops in the form of rain or mist. This method has long been used in the irrigation of lawns in western cities. When one considers the high rates charged by companies and municipalities for domestic water supplies and the large percentage of such supplies which is used for sprinkling lawns, he is surprised at the crudeness and inefficiency of the equipment and methods employed.

In recent years successful attempts have been made not only to improve the practice of spray irrigation but to extend its use to gardens and fields. In outlining its broader scope in the irrigation of fields, the writer has been guided by the recommendations made by Milo B. Williams Irrigation Engineer, Bureau of Public Roads, U. S. Dept. of Agri., to eastern irrigators in assisting them to install suitable plants for the irrigation of small areas throughout the humid region. These plants are designed to supplement a scanty or unequal and always uncertain rainfall by furnishing relatively small quantities of water to truck, small fruit and orchards at the right time. The large profits derived from such crops, the high cost of artificial fertilizers, the uneven character of the surface of fields, the growing of two or more crops on the same field in one season, and the advantages of being able to control the soil moisture in cultivating and recropping fully justify, under favorable conditions, the heavy expense.

The essential features of every system designed for spray irrigation are (1) nozzles, (2) feed pipes and (3) a pumping plant or its equivalent. The design of nozzle and its arrangement in the field separate the types of spray irrigation into three more or less distinct groups which are herein briefly described under the following heads.

Portable Nozzle Type.—This consists of sets of nozzles and hose which can be moved from place to place and attached to hydrants conveniently located throughout the field. The hydrants are generally spaced 100 to 200 feet apart and each controls an area of proportionate size. The hydrants are usually made of a short length of pipe projecting 2 or 3 feet above the surface and capped with spigot or hose connection. In some cases special hydrants are used. The portable nozzles are attached to lengths of hose which reach at least one-half the distance between the hydrants. For garden or lawn irrigation a 3/4-inch hydrant and hose can be used. Grass sods, such as putting greens, public parks, and meadows are often irrigated with larger hose ranging up to 2 1/2 inches in diameter.

Some gardeners prefer to dispense with the nozzle in spraying greenhouse plants and seed-beds, and merely pinch the end of the hose between the fingers in such a way as to produce the desired spray. There are a number of adjustable nozzles on the market which can be made to discharge a solid stream or any degree of fineness of spray. One type requires to be held constantly in the hand or moved very frequently. Another type which sprays a circular area can be set in one place and allowed to run for some time before moving is necessary. The last type is generally supported on a stool or sharp-pointed rod which can be stuck into the ground and the nozzle held 3 or 4 feet above the surface.

Where a large quantity of water is to be applied through a large hose, a rotating nozzle mounted on a small truck meets the requirements. These nozzles discharge from 60 to 100 gallons per minute under a 30-pound pressure and cover a circular area 75 to 100 feet in diameter.

Stationary Nozzle Type.—The stationary type of spray irrigation consists of a system of equally spaced nozzles over the field so that any portion can be sprayed by turning on the water. The feeder system forms a network of piping so constructed that the nozzles are about 30 feet from each other and set on the "diamond." This makes the circular areas covered by the nozzles fit together with the least overlapping and yet cover the bulk of the ground. The nozzles are placed on 3/4-inch risers 5 to 6 feet above the surface. The nozzles commonly used may be

divided into three groups, *viz.:* (1) solid nozzles with no moving parts, (2) adjustable nozzles with parts which can be manipulated to change their capacities or degree of spray, and (3) rotary nozzles with moving parts which assist in the distribution of the water by centrifugal force.

The capacities of some of the popular nozzles were found by actual test to be from 3.2 to 14.5 gallons per minute when operating under 20 pounds pressure per square inch, and from 3.5 to 18.4 gallons under 25 pounds pressure. The circular areas covered by the different nozzles varied from 30 to 40 feet in diameter. The distribution of water over the areas was somewhat uneven. Most nozzles discharge a relatively large percentage of the water in an annular ring from 10 to 30 feet in diameter, with gradual reductions inside and outside of this ring.

The solid nozzles with no moving parts are the most durable. Their capacities and form of spray can not be varied as in the case of the adjustable nozzle. The solid nozzles which will give a wide lateral throw are of large capacities and demand large feeders.

Rotary nozzles throw the greatest distance in proportion to their capacities but in larger drops. A certain amount of wear takes place which in time reduces their efficiencies.

Adjustable nozzles are favored by some truck gardeners because of the fine spray which can be obtained when desired. The throw is usually less than either the stationary or rotary nozzle.

Overhead Nozzle Lines.—The system commonly known as overhead spray irrigation consists of a series of nozzles inserted in parallel pipe lines supported above the surface on posts in such a way that each line is fed from a main at one end and irrigates a strip from 50 to 56 feet in width the length of the field (see Plate II).

A nozzle line is made of galvanized wrought-iron or steel pipe into the shell of which is screwed at regular intervals small brass nozzles. The pipe is supported in bearings which will permit it to be revolved, thus throwing the nozzles from side to side. The nozzles are accurately set in a straight line so that all will discharge in the same direction and irrigate a strip parallel to the pipe when the line is set in any one position. Consecutive strips

can be irrigated by revolving the pipe through an arc at different stages until the entire area on both sides is covered. Each nozzle throws a clear-cut solid stream which becomes broken into small drops before reaching the ground. A nozzle line is connected to the feed pipe by means of a riser, elbow, patented turning union, and nipples. A quick-opening lever gate valve is placed in the riser at a convenient height. The lines are operated from the feeder end by a hand- or power-turning device.

The nozzle lines should run in the direction of cultivation so that the crop rows will parallel the pipe supports. The feeder pipe should run underground at right angles to the nozzle lines and be so located as to use the least amount of large pipe.

The size of pipe to use in a nozzle line is determined by the number and capacities of the nozzles it contains. The end connecting to the feeder is the larger to carry all the water but as the water is diminished by the nozzles the pipe can be made smaller in proportion to the amount withdrawn.

The following table illustrates the sizes of pipe used in nozzle lines of different lengths for a nozzle having a capacity of 1/5 gallon per minute and a spacing of 4 feet.

Table No. 25

Total length, feet	Proportioned sizes and lengths of pipe				
	3/4 inch	1 inch	1 1/4 inch	1 1/2 inch	2 inch
100	100				
150	90	60			
200	90	110			
300	90	150	60		
400	90	150	160		
500	90	150	150	110	
600	90	150	150	150	60
700	90	150	150	150	160
800	90	150	150	150	260

Nozzle lines are usually spaced 50 to 56 feet apart and operated under 30 pounds pressure. When it is desired to irrigate more rapidly larger pipe lines and nozzles must be used or the small nozzles may be spaced closer together on a larger pipe. It seldom

FIG. A.—Overhead spray irrigation showing piping.

(*Facing page 160.*)

PLATE II

FIG. B.—Enlarged view of overhead nozzle line.

pays to use 2-inch pipe in nozzle lines but is cheaper and better to run more feeders.

There are two popular methods of supporting nozzle lines, *i.e.*, directly on posts or suspended from a high cable. A post which will hold the pipe just above the crop or one that elevates the line 6 1/2 feet above the surface so a horse can pass under are the common designs. The higher design permits cross-cultivation and is popular among truck farmers and berry growers, while the low posts place the system less in sight for flower beds, lawns and small home gardens. The posts should be of concrete, pipe or wood treated with asphaltum, tar or paint. They should be 5 to 6 inches at the base if of wood, and set in the ground 2 1/2 to 3 feet and of ample length to be cut off at the right height after set to give the nozzle lines uniform appearance. Nozzle lines should be supported every 18 feet.

Suspending the nozzle lines from a high cable supported on large posts is a construction used by some farmers because of the lessened obstruction to cultivation. The posts are spaced from 75 to 100 feet apart and may be either of wood or 4-inch steel pipe. They should be from two to three times as high as the pipe is to be held. The cable is held on the tops of the posts by heavy hooks but free to draw lengthwise. Heavy spreading anchors must hold the ends of the cable which are generally fastened to buried logs or concrete. A turn buckle should be inserted near the end of the cable for use in taking up the slack at different times. The proper weight of cable to use depends upon the spacing and height of the posts and the weight of pipe to be supported. These facts should be furnished to the cable dealer and a sufficient weight used.

The nozzle line is suspended from the cable by varying lengths of galvanized wire spaced 15 feet apart and fastened to hooks in which the pipe lies. The nozzle lines can be graded uniformly by adjusting the lengths of the wire hangers. Cable suspension generally costs 15 to 20 per cent more than direct post support.

Feeder System.—The designing of a feeder system should be governed by the type of nozzles used, their individual capacities and the amount of water to be carried through each line. The field should be divided into irrigation units. The size of units will be limited either by the available water supply or by the

rate of irrigation desired for the entire field. The main feeder should be located to make it as short as possible and at the same time intersect the branch feeders at the most efficient points. The capacity of the main should be equal to that of the pump and that needed for one irrigation unit. The main can be reduced in size as the water is diminished by branches in the most remote unit.

The branch feeders should be of capacities to supply their respective nozzles and reduced in size to correspond with the amount of water to be carried at different points. No pipe should be small enough to generate excessive frictional resistance.

The following table gives the size of metal pipe to use for different quantities of water in order to keep the frictional resistance within moderate limits, for straight pipe lines under 500 feet in length. For longer lines it is generally advisable to increase the sizes to the next larger. Allowance should also be made for any sharp bends.

TABLE No. 26

Gallons per minute	Size of pipe, inches	Gallons per minute	Size of pipe, inches
5	1	350	5
10	1 1/4	400	6
20	1 1/2	500	6
30	2	600	7
50	2	700	7
75	2 1/2	800	8
100	3	900	8
150	3 1/2	1,000	9
200	4		
250	4		
300	5		

The pipe used for feeder systems consists of common steel or wrought-iron water pipe with threaded joints, or cast-iron pipe with leaded joints, or riveted steel pipe with flange or bolted joints. Reinforced concrete pipe can also be used for this purpose if it is properly made and the pressure is carefully regulated.

Steel pipe should be galvanized and the exposed threads on both steel and wrought iron should be painted. Black guaran-

teed wrought-iron pipe is more durable than steel and often used in preference to galvanized steel. The rust which forms on black pipe may give some trouble in filling nozzles. It is customary to use steel or wrought-iron pipe in sizes up to 5 or 6 inches. Cast-iron pipe becomes cheaper for larger sizes unless it must be shipped long distances. Cast iron is the most durable of these metal pipes and may be used in the lightest weights made. Riveted steel pipe is light in weight and comes in long lengths making it the cheapest to lay. This pipe if well galvanized after making is good to use when long shipments and large pipe are necessary.

All feeder systems should be put underground below the depth of cultivation where possible, and ample provision should be made for draining in winter and for flushing out once or twice per year to blow out rust scales, sediment, etc. This is best accomplished by having removable plugs at the end of each main and feeder and at all low points in all lines.

Pumping Plants.—The four factors to be considered in designing a pumping plant for spray irrigation are the amount of water to be pumped per minute; the static head, or vertical distance between the level of the water supply and the highest nozzle; the friction and velocity heads or the total resistance to the water passing through the pipe lines; and the pressure head, or the amount of pressure necessary to operate the nozzles.

The capacity of the plant should be the same as that of the feeder system (see page 162). The static head should be determined by a survey in the field with an engineer's level and due allowance made for the distances the water level may be lowered when pumping as well as the height of the nozzles above the ground. The frictional and velocity heads can be obtained from hydraulic tables when the kind, size and length of pipe and the amounts of water are known. The pressure head is determined by the type of nozzle used.

Knowing the capacity and the sum of the heads, the amount of work which the plant must perform is determined and the horsepower can be calculated to correspond to the guaranteed efficiency of the pump to be used.

The most desirable type of pump to use in any one case must be determined by the above factors and any restricting conditions

of the water supply, such as a deep well, water containing sediment, etc. All factors and conditions should be furnished to several manufacturers so that they can bid on their most adaptable machinery, and the farmer obtain the most efficient equipment for the expenditure.

Power displacement pumps of the piston and plunger types, and high-pressure centrifugal pumps are the designs commonly used for spray irrigation plants.

The single cylinder displacement pumps are adaptable to small plants up to 75 gallons per minute, where the water is within 25 feet of the pump. This type is sometimes the only one advisable to use in deep wells for any quantity of water. The piston should be double acting and lift water when moving in either direction. The pump should be equipped with a large air chamber which will act as a cushion and reduce the pulsations of the water in the pipe lines to a minimum. The power head and cylinder are built in a compact unit for low suction lifts but must be separated for deep well use. In the latter case it is best to have the cylinder always under water if possible.

The duplex and triplex displacement pumps are adaptable for pumping any quantity of water where the suction lift is within 25 feet. These pumps are built in both single- and double-acting types. Light-weight double-acting duplex and single-acting triplex are commonly used. Smaller air chambers in comparison to the amount of water can be used than on simplex pumps as the multicylinders give a more steady discharge. These pumps are considered the most efficient types when kept in repair and direct-connected to the engine. The connection to the engine should be made by a friction clutch which can be thrown in or out at will when the engine is running. A belt connection can be used where desirable but takes more floor space and more power is lost in transmission. A direct-connected unit is the most efficient and compact construction. The reduced power necessary to run an efficient high-priced pump may make it cheaper to install and operate than a belt-connected inexpensive pump which demands a larger engine and house.

Centrifugal pumps can be used to advantage for spray irrigation under some conditions. Large centrifugal pumps are more efficient than small ones. Centrifugal pumps also decrease in

efficiency as the head against which they must work increases. Therefore, the larger the plant and the lower the lift the more adaptable is a centrifugal pump. Where the total head does not exceed 100 feet a single-stage high-pressure pump may be used. These pumps should be built for high speed with long bearings and adequate oiling facilities. Two-stage centrifugal pumps should be used for heads between 100 and 250 feet as they can be run at lower speeds than the single stage for like heads.

The efficiency of a centrifugal pump may not be as high in the beginning as a good displacement pump but unless the displacement pump is kept in the best of repair its efficiency is apt to drop below that of the centrifugal which maintains its efficiency longer under wear. The centrifugal is the simplest of pumps and the repair bills are correspondingly small. It is seldom that a centrifugal can be direct connected to the motive power unless the power is electricity in which case the centrifugal should always be considered.

Sprinkling Citrus Orchards in Southern California.—In recent years (1922 to 1925) a considerable number of citrus groves in several localities of southern California have been irrigated by spraying methods. The horizontal overhead pipe with its perforations into which brass nozzles are inserted is not used. All spraying is done by solid or rotary sprinklers, and the systems are said to be permanent, portable or semi-portable. In the permanent systems, small piping is laid beneath the surface of the orchard along every second, third or fourth tree row. Sometimes this piping is laid midway between tree rows, at other times along the edge of the tree row. Then vertical pipes called "risers" with a sprinkler attached to the upper end of each are installed at equidistant points on each pipe lines. Each riser is equipped as a rule with a valve to regulate the pressure and also with a strainer to catch sediment or scale from the pipe. The installation of a riser is shown in Fig. 70.

To lessen the first cost of installing so many risers and to reduce the number of pipe lines, portable risers attached to short lines of hose are used. These portable stands are shown in Fig. 71.

[1] The data and illustrations for this topic were furnished by Prof H. A. Wadsworth of the University of California.

The semi-portable method usually consists in laying a pipe line along every sixth tree row and equipping these with risers and also with garden hydrants at every sixth tree. In other cases a permanent feed-pipe line is laid through the middle of the orchard and laterals laid on the surface of the ground convey the water to portable hydrants.

FIG. 70.—Detail of sprinkler installation.

FIG. 71.—Typical portable stand used in portable and semiportable installations.

Experience and a knowledge of hydraulics are necessary in laying out sprinkler systems. The maintenance of the required water pressure of from 35 to 45 pounds per square inch in the pipe lines, the friction in the pipes, proper size of pipe to deliver, say, 10 gallons per minute, spacing of the risers, topography

and water requirement of the orchard, all need to be carefully considered.

It costs about $300 an acre to install a permanent sprinkling system. The labor involved in operation is small but interest and depreciation amount to about $25 per acre per annum.

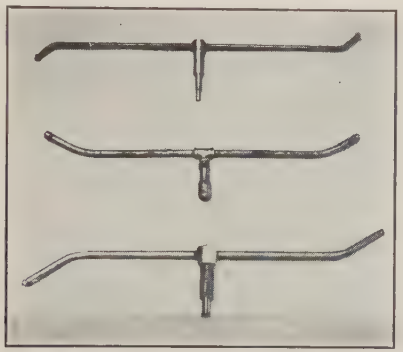


FIG. 72.—Typical rotary heads for orchard irrigation.

Investigations made to determine the quantity of water used by the sprinkling method as compared with the more common furrow method show that somewhat more water is used in furrow irrigation. The greater loss of water by evaporation in the sprinkling method has not been determined or estimated.

Typical rotary heads designed for orchard irrigation are shown in Fig. 72.

CHAPTER V

WASTE, MEASUREMENT, DELIVERY AND DUTY OF WATER

31. The Low Efficiency of Irrigation Water.—According to the census the area of land irrigated in the United States in 1919 was 19,191,716 acres. The quantity of water diverted from streams and other sources of supply is not so well known but from partial returns to the census, it would appear to be about 5 acre-feet per acre per annum. On this basis nearly 96,000,000 acre-feet are diverted annually for agricultural purposes. Some idea of the magnitude of this volume of water may be formed by stating that if spread evenly over a territory the size of the state of New York it would cover it to a depth of nearly 32 inches.

To convey so much water often from distant sources and distribute it over cultivated land renders necessary a large number of canals and ditches. These channels are for the most part excavated in earth and except in a few cases a large percentage of the water which flows through them is lost by absorption and percolation along the route. Coupled with the transmission losses are to be found other losses arising from improper methods of use and lack of skill in applying water. An estimate of all losses based on water measurements and experiments shows that for every 3 gallons of water diverted from natural streams, only about 1 gallon subserves a useful purpose in nourishing plant life. In other words, the general average efficiency of irrigation water is less than 35 per cent. The waste which lowers the efficiency to one-third the maximum is all the more to be deplored by reason of the fact that irrigation water so valuable to the West is rapidly becoming scarce while fertile raw land without a water right is plentiful and cheap. Based on the acreage which a unit of water now serves, it is doubtful if more than 50,000,000 acres can ever be irrigated. The census returns for 1919 show that in the 17 states comprising the arid region, 200,000,000 acres were classed

as improved farm lands. Just how much more land can be improved of the total extent of arable land in the West is not known. This much, however, is certain, that when every gallon of the available water supply is economically used, vast areas of rich farming lands will be unreclaimed for lack of water.

32. Waste of Water Due to Seepage and Other Causes.—The largest loss of irrigation water is due to the well-nigh universal practice of conducting it in earthen ditches. In 1919, the census enumerators reported 109,174 main and lateral ditches aggregating 159,864 miles in length. At that time probably less than 5 per cent of the total length was lined, or otherwise made impervious, thus leaving nearly 152,000 miles of earthen channels.

Seepage Losses.—Opinions differ as to the relative merits of the two methods of expressing seepage losses in canals. One method expresses the loss per mile in the percentage of flow of the canal while the other expresses the loss in 24 hours in terms of cubic feet per square foot of wetted area. Both of these methods have their merits. The former gives one a ready grasp of the efficiency of a canal in a general way, while the latter permits a more detailed estimate of the loss which may be expected from a given section of a canal when the conditions existing in it have been carefully studied.

It is not within the scope of this publication to include a detailed discussion of the various factors influencing seepage, but in order to form a reliable estimate of the loss by seepage from a proposed canal, the principal factors should be carefully considered. Briefly these are:

1. Size, shape and character of the particles of material in the soil and subsoil of the proposed canal location.
2. Manner in which these particles are mixed and the proportion of fine material in the mixture.
3. Rate at which silt is likely to be deposited.
4. Extent, if any, to which colloids will be present in the silt or canal water.
5. Relation which the wetted perimeter of the canal bears to other hydraulic elements, more particularly the discharge.
6. Depth and velocity of water in canal.
7. Extent of capillary movement of water from canal.
8. Withdrawal of water by capillary syphon action and gravity.

9. Inflow of seepage water.
10. Temperature of the soil and water.
11. Nearness to a ground-water table.
12. Cross-sectional slope of the canal location.

Table No. 27 shows the close relation existing between the unit loss as expressed in percentage of flow and the size of a canal. It has been compiled from data obtained from various sources which have been published in *Bull.* 126, U. S. Department of Agriculture, by the author. It is interesting to note the fairly constant decrease in the average loss in per cent per mile as the capacity increases.

Table No. 27

Capacity of canal, second-feet	Number of tests	Average loss per mile, per cent
Less than 1	16	25.7
1 to 5	37	20.2
5 to 10	30	11.7
10 to 25	49	12.1
25 to 50	48	5.5
50 to 75	31	4.3
75 to 100	26	2.7
100 to 200	45	1.8
200 to 800	27	1.2
800 and over	14	1.0

Prevention of Seepage Losses.—Seepage losses in porous channels may be greatly lessened by a lining of impervious material, such as clay or fine silt. Sometimes the beds of such channels contain more or less fine material mixed with the coarse and puddling may then be used to advantage. Puddling can best be done by making use of the canal after being moistened as a temporary feeding ground for sheep or goats. Whenever the material is too coarse to puddle, good puddling material may be hauled and spread over the surface of the canal. It is then moistened and tamped or puddled by the feet of domestic animals. After securing a clay lining in this manner it is well to ram coarse gravel into the surface, thereby making a clay concrete.

In all irrigation channels except those subject to erosion, a gradual sedimentation takes place which renders them more impervious with age. Whenever water of silt-laden streams is run through canals the bottom soon becomes quite impervious necessitating frequent removal by cleaning. In fact the discharge of all streams subject to floods carries during periods of high water more or less silt, a part of which is deposited in the artificial channels and tends to make them watertight.

At a time when lumber was cheap and Portland cement expensive it was common practice to line the weak and leaky beds of canals with lumber in the form of flumes. The short life of wood, particularly when in contact with earth, the high cost of maintenance, the rapid increase in the price of lumber and the corresponding decrease in the price of cement have all tended to lessen the use of wooden linings.

It pays to prepare as stable and impervious a channel as possible with the materials at hand since the cost is low, the efficiency of the channel increased and a foundation laid for a concrete or other lining.

Before lining a canal or any part thereof careful consideration should be given to each of the main factors involved in the investment. There is, in the first place, the quantity of water lost by seepage in the canal as a whole or in its most leaky portion, the value of this water and the cost of a lining. Usually other questions arise as to the cost of recovering the seepage water, the damage it may do to land and the cost of reclaiming seeped lands.

The lining of canals with concrete is generally regarded as the best and most economical means of greatly lessening if not preventing seepage losses. The thickness of concrete lining used in the West varies from 1 1/2 to 4 inches. Thinner linings of 1 inch in thickness are usually made of cement mortar. A 2-inch lining made of concrete composed of 1 part of cement to 5 of sand and gravel, hand placed, costs from 9 to 12 cents per square foot. A lining 1 1/2 inches thick composed of 1 part of cement to 4 of sand and fine gravel laid by the gunite process costs about the same.

About 20 years ago, a mixture of asphalt was used to line ditches, but with little success. In recent years, however, much has been

done by way of experimenting to correct former imperfections, and the modern asphalt lining may prove a worthy competitor of concrete. The mixture which is considered the most suitable is a modification of that used in street and road paving, but contains more asphalt, less filler and coarser sand. The percentage of asphalt of D grade runs from 13 to 15 and copper sulphate is added in the proportion of 17 to 5,000 of the weight of the mixture. The material as it leaves the asphalt plant has a temperature of 300°F. and is transported and dumped on canvas on the canal bank and then shoveled on the sides and bottom of the canal. It is then raked and rolled. Before applying the lining material the surface of the canal is sprayed with cresol.

Up to the present, a thickness of lining of 1 1/2 inches has been used but when the process is perfected it is believed a thickness of 1 inch will meet all requirements. Contracts for the thicker lining run about 9 cents per square foot.

In studying canal seepage and its prevention in California, Major O. V. P. Stout found in many cases large losses of water from concrete-lined canals. In all likelihood the greater part of the leakage was due to imperfect joints. This and other outstanding features of this subject would lead one to believe that the canal lining of the future will have a base of concrete but that the surface coating and especially the joints will be of asphalt.

A Flat Rate per Acre Causes Waste.—In the most common form of water-right contract between the owners of a canal system and the water users, the former agree to deliver a fixed quantity of water for a definite area of land. This ratio between a unit of water and a certain number of acres of land is known as the duty of water and is usually determined while the land is in its raw state and before the real needs of soil and crops as regards water have been ascertained. As a result of a random guess at the average duty over large tracts, some water users receive under their contracts more water than they can use economically, while others may receive too little. The farmers have no incentive to economize in the use of water since their payments are based on a flat rate per acre. More than this, the combined efforts of the latter class are usually exerted in inducing the company to increase the quantity delivered.

Wherever it is practicable, irrigation water should be measured out to users in the same way that water for domestic purposes is metered out to consumers and let each pay for what he gets. Experiments have repeatedly shown that where water is delivered under a quantity rate, much less is used at no sacrifice to the yields of crops.

If the quantity rate per acre cannot be adopted, it is usually feasible to form such a combination of the two methods as will serve the same purpose. In this combined method a minimum quantity of water per acre must be paid for by all users but to those who use more an additional charge is made for all excess. This method is in use notably on some of the Federal reclamation projects. For example, on the Grand Valley Project in Colorado, the charge for water in 1921 was $2 per acre, which entitled the user to 2 acre-feet, and for water in excess of this amount a charge was made of $1 per acre-foot. In 1922 on the same project these respective charges were $1.50 and $0.75.

Continuous Delivery Wastes Water.—A continuous flow during the irrigation season may be delivered to large farms with only normal waste but in the case of small or medium-sized farms rotation should be practised in the interests of economy. The needs of the average crop for water vary greatly between seed time and harvest and a water-right contract which calls for a continuous delivery of a fixed volume of water from early spring to late fall is not only wrong in principle but wasteful of water. Instead of a continuous flow water contracts might better provide for the delivery at stated periods during each season of a definite quantity of water preferably expressed in acre-feet per acre. In the case of stored water, well water, or other constant sources of supply, the delivery might be made on demand of the user after due notification. A system of this kind would insure the delivery to the farmer of the proper amount of water at the right time.

Other Losses of Water.—The waste of water caused by evaporation from irrigated fields, deep percolation, uneven distribution, poorly prepared fields, imperfect methods of application and unskillful use will be treated under other headings.

33. Measurement of Water.—The necessity for measuring the water delivered to irrigators is now generally recognized throughout the arid region. While many irrigation enterprises

still do without such measurements, the increasing value of water and the gradual establishment of the principle that irrigators should pay for the quantity of water used rather than for the number of acres irrigated are forcing measurements on the well-managed systems. Above all, wise farm measurement requires that irrigators should know by actual measurement whether they are receiving the water for which they are paying from 50 cents to $20 or more per acre-foot.

The measurement of water is a large subject. To treat it fully would require a volume in itself. The parts of the subject herein considered will, therefore, be limited to a brief presentation of those features which concern the irrigator and more particularly the devices and methods which he can employ in the purchase, delivery and use of water.

Units of Measure.—A number of standard units are used in the measurement of water. Other units and terms more indefinite in character are likewise in common use in certain localities and both kinds are herein defined.

1. *Cubic Foot per Second.*—This standard unit, usually abbreviated to second-foot in America and to cusec in British India, represents the quantity of water flowing through a flume or other channel 1 foot wide and 1 foot deep with a mean velocity of 1 foot per second of time.

2. *Acre-foot.*—As the term implies, an acre-foot is the volume which will cover 1 acre 1 foot in depth and is equivalent to 43,560 cubic feet. An acre-inch is one-twelfth of an acre-foot.

3. *U. S. Gallon.*—The U. S. gallon contains 231 cubic inches.

The three units just described are standard in this country but those which follow vary with the state or locality.

4. *Miner's Inch.*—This unit represents the quantity of water which will flow through an orifice 1 square inch in area under a given head of water. Since the head varies with the prevailing custom of different localities, the miner's inch likewise varies.

5. *Head of Water.*—The quantity of water which is turned into a farmer's supply ditch is usually termed a head. The same term is used to designate the quantity used to irrigate a field. While the head of water is, as a rule, quite uniform over any given canal system it varies between wide limits among systems and states. In Utah a head of water is called an "irrigating stream."

6. *An Irrigation.*—Equally indefinite is the term "irrigation" when used to represent the quantity of water applied to land at any one time. A light irrigation may not exceed 2 acre-inches per acre, whereas a heavy irrigation often exceeds 6 acre-inches per acre.

Unit Equivalents.—In converting from one unit to another the volumes carried in ditches, stored in reservoirs, pumped from wells or spread over the land, the following table of equivalents may be found convenient:

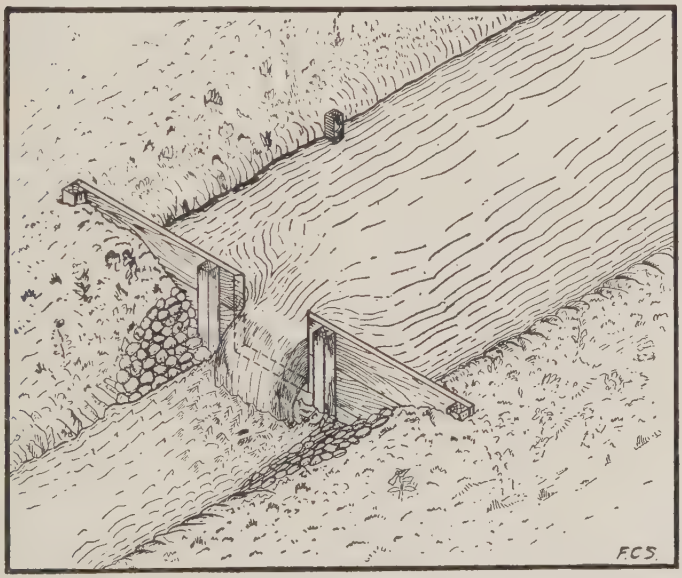


Fig. 73.—Rectangular weir.

1 cubic foot equals 7.48 gallons.
1 cubic foot of water weighs 62 1/2 pounds.
1 second-foot equals about 1 acre-inch per hour.
1 second-foot equals 1.983 acre-feet per day.
1 second-foot equals 448.8 gallons per minute.
1 second-foot equals 646,272 gallons per day.
1 acre-foot equals 43,560 cubic feet, equals 325,850 gallons.
1 acre-inch equals 3,630 cubic feet, equals 27,154 gallons.
50 miner's inches equal 1 second-foot in southern California, Idaho, Kansas, New Mexico, North Dakota, South Dakota, Nebraska and Utah.

40 miner's inches equal 1 second-foot in central California, Arizona, Montana and Oregon.

38.4 miner's inches equal 1 second-foot in Colorado.

Volumetric Measurement.—Springs, ditches or small streams may be diverted into a vessel of known capacity and the discharge determined by noting the time required to fill the vessel. Larger flows may be diverted into tanks or reservoirs and measured by ascertaining the cubical contents of that part of the tank or reservoir which is either filled or emptied in a given time.

Weirs.—The weir (Fig. 73) is one of the most common devices for the measurement of farm-water supplies. It is accurate, cheap and easy to install. Conditions, however, are frequently encountered which prevent its use or lessen its efficiency. It is not a suitable device to measure the water of silt-laden streams owing to the rapid deposit of silt on the up-stream side of the weir. In other cases the grade of the ditch may be too flat to permit of the necessary fall of water from the notch. Even under the most favorable conditions it is liable to become defective and give inaccurate results.

There are three types of farmers' weirs, rectangular, trapezoidal and triangular, depending on the form of weir notch. In measuring water accurately by the use of any one of these types, it is desirable to reduce the velocity of water to a minimum as it approaches the weir. To accomplish this a small pond is formed on the upstream side of the weir. This can be done readily and cheaply in earth as may be seen from Fig. 73. An automatic water register is useful for recording the height of water flowing over the weir.

Where a slight error in measuring water is permissible the weir pond may be reduced in area and a corresponding reduction made in the dimensions of the weir box. This change will be apt to cause the water to approach the weir with some velocity but if this velocity does not exceed 0.5 foot per second the results of the measurement as given in Table No. 28 for Cipolletti weirs are likely to be sufficiently accurate for farm supplies.

TABLE No. 28.—DISCHARGE OVER CIPOLLETTI WEIRS

Head of water		1-foot weir		2-foot weir		3-foot weir	
Feet	Inches	Cubic feet per second	Gallons per minute	Cubic feet per second	Gallons per minute	Cubic feet per second	Gallons per minute
0.11	1 3/8	0.123	55.3	0.25	112.4	0.37	161.2
0.12	1/2	0.140	63.0	0.28	125.9	0.42	188.8
0.13	9/16	0.158	71.0	0.32	143.8	0.47	211.2
0.14	5/8	0.176	79.2	0.35	157.3	0.53	238.2
0.15	3/4	0.196	88.1	0.39	175.3	0.59	265.0
0.16	1 7/8	0.216	97.2	0.43	193.3	0.65	292.1
0.17	2	0.236	106.1	0.47	211.2	0.71	319.0
0.18	1/8	0.257	115.5	0.51	229.1	0.77	346.0
0.19	1/4	0.279	125.5	0.56	252.0	0.84	377.5
0.20	3/8	0.301	135.2	0.60	269.5	0.90	404.0
0.21	2 1/2	0.324	145.5	0.65	292.1	0.97	436.0
0.22	5/8	0.347	156.0	0.69	310.0	1.04	468.0
0.23	3/4	0.371	166.8	0.74	332.5	1.11	499.0
0.24	7/8	0.396	178.0	0.79	355.0	1.19	535.0
0.25	3	0.421	189.1	0.84	377.5	1.26	567.0
0.26	3 1/8	0.446	200.5	0.89	400.0	1.34	602.5
0.27	1/4	0.472	212.0	0.94	422.0	1.42	638.0
0.28	3/8	0.499	224.5	1.00	450.0	1.50	674.0
0.29	1/2	0.526	236.5	1.05	472.0	1.59	711.0
0.30	5/8	0.553	249.0	1.11	499.0	1.66	746.0
0.31	3 3/4	0.581	261.1	1.16	522.0	1.74	782.0
0.32	7/8	0.609	274.0	1.22	548.0	1.83	823.0
0.33	4	0.638	287.0	1.28	576.0	1.91	858.0
0.34	1/8	0.667	300.0	1.33	598.0	2.00	899.0
0.35	1/4	0.697	313.0	1.39	625.0	2.09	940.0
0.36	4 3/8	0.727	327.0	1.45	652.0	2.18	980.0
0.37	1/2	0.758	341.0	1.52	683.0	2.27	1,020.0
0.38	9/16	0.789	354.5	1.58	711.0	2.37	1,065.0
0.39	5/8	0.820	368.7	1.64	737.0	2.46	1,106.0
0.40	3/4	0.852	383.0	1.70	764.0	2.56	1,151.0
0.41	4 7/8	0.884	397.0	1.77	796.0	2.65	1,191.0
0.42	5	0.916	412.0	1.83	822.0	2.75	1,238.0
0.43	1/8	0.949	426.0	1.90	854.0	2.85	1,282.0
0.44	1/4	0.983	442.0	1.97	885.0	2.95	1,326.0
0.45	3/8	1.016	455.5	2.03	912.0	3.03	1,370.0
0.46	5 1/2	1.050	472.0	2.10	944.0	3.15	1,412.0
0.47	5/8	1.085	487.5	2.17	976.0	3.25	1,460.0
0.48	3/4	1.120	504.0	2.24	1,008.0	3.36	1,511.0
0.49	7/8	1.155	519.0	2.31	1,038.0	3.46	1,555.0
0.50	6	1.190	535.0	2.38	1,070.0	3.57	1,605.0

DISCHARGE OVER CIPOLLETTI WEIRS.—*Continued*

Head of water		1-foot weir		2-foot weir		3-foot weir	
Feet	Inches	Cubic feet per second	Gallons per minute	Cubic feet per second	Gallons per minute	Cubic feet per second	Gallons per minute
0.51	6 1/8	.....	.....	2.45	1,101.0	3.68	1,655.0
0.52	1/4	.....	.....	2.52	1,132.0	3.79	1,695.0
0.53	3/8	.....	.....	2.60	1,169.0	3.90	1,753.0
0.54	1/2	.....	.....	2.67	1,200.0	4.01	1,800.0
0.55	5/8	.....	.....	2.75	1,235.0	4.12	1,850.0
0.56	6 3/4	.....	.....	2.82	1,268.0	4.23	1,905.0
0.57	7/8	.....	.....	2.90	1,303.0	4.35	1,955.0
0.58	7	.....	.....	2.97	1,335.0	4.46	2,005.0
0.59	1/8	.....	.....	3.05	1,371.0	4.58	2,060.0
0.60	1/4	.....	.....	3.13	1,408.0	4.69	2,109.0
0.61	7 3/8	.....	.....	3.21	1,441.0	4.81	2,160.0
0.62	1/2	.....	.....	3.29	1,480.0	4.93	2,220.0
0.63	9/16	.....	.....	3.37	1,515.0	5.05	2,270.0
0.64	5/8	.....	.....	3.45	1,550.0	5.17	2,322.0
0.65	3/4	.....	.....	3.53	1,587.0	5.29	2,380.0
0.66	7 7/8	.....	.....	3.61	1,622.0	5.42	2,435.0
0.67	8	.....	.....	3.69	1,659.0	5.54	2,490.0
0.68	1/8	.....	.....	3.78	1,700.0	5.66	2,545.0
0.69	1/4	.....	.....	3.86	1,735.0	5.79	2,602.0
0.70	3/8	.....	.....	3.94	1,771.0	5.92	2,660.0
0.71	8 1/2	.....	.....	4.03	1,815.0	6.04	2,715.0
0.72	5/8	.....	.....	4.11	1,850.0	6.17	2,771.0
0.73	3/4	.....	.....	4.20	1,888.0	6.30	2,830.0
0.74	7/8	.....	.....	4.29	1,930.0	6.43	2,892.0
0.75	9	.....	.....	4.37	1,965.0	6.56	2,850.0

THE MINER'S INCH.—This method of measuring water was in common use in the West during the early mining period and under the conditions which then prevailed it was probably the best that could be devised. Since, however, it can be used only to measure small streams, its use for this and other reasons has now become restricted to a few localities. Formerly each mining camp adopted its own standard "inch" but in more recent times nearly all the local standards have been combined into two kinds. In one of these the depth or head of water above the center of the opening is 4 inches and in the other it is 6 inches. The opening is usually 2 inches measured vertically. In the first-named kind, if the slide which controls the opening is pulled out so as to

leave an opening 2 inches vertical by 25 inches horizontal, the discharge would be 50 miner's inches or an equivalent of 1 second-foot. In the last-named kind, owing to the greater head, if the slide is pulled out 20 inches so as to leave an opening 2 by 20 inches the discharge would be 40 miner's inches or an equivalent of 1 second-foot.

Submerged Orifice.—Water may be measured as it passes through a submerged opening in a gate or other structure by ascertaining the difference in elevation of the water surface on each side of the gate and adopting the proper coefficient of discharge through the opening. The former is readily obtained but the latter usually varies with each structure installed. In some types of submerged orifices an attempt is made to provide contraction on the bottom and sides of the opening but a contraction on the bottom soon fills with débris or sediment and this change in condition causes an over-registration of water.

Another frequent cause of error in this form of measuring device is due to the fact that the water may approach the opening with more or less velocity which likewise causes an over-registration.

A gate or box containing a submerged opening should be so planned and installed that there will be complete contraction on each side but no contraction on the bottom. The velocity of approach should also be eliminated as far as practicable and the whole device standardized, so as to cause the least change in conditions while in use. The discharge in second-feet may be computed from the equation $Q = CA\sqrt{2gh}$ where Q is the discharge in second-feet, C a constant ranging from 0.65 to 0.85, A the area of the orifice in square feet, g the acceleration of gravity in feet per second and h the head in feet.

This mode of measuring water used in irrigation is well adapted to silt-laden water supplies and to localities with insufficient fall to justify the installation of weirs.

Proportional Division of Water.—In some states, notably Utah, not only the water carried by canals but also the discharge of the smaller streams is frequently allotted to the users in proportional parts of the entire flow. The basis of allotment is the number of shares of stock owned by each user, each share often representing an acre of irrigable land. Since western streams

and to a considerable extent western gravity canals are subject to wide fluctuations in the volumes carried, there is a decided advantage in using this method. Its chief defect is due to a disregard of transmission losses which results in allotting too much water to the upper users of a system and too little to the lower users. An equitable apportionment of the available or net flow can be effected only by first deducting all losses due to transmission, a method which requires the measurement rather than the proportioning of water.

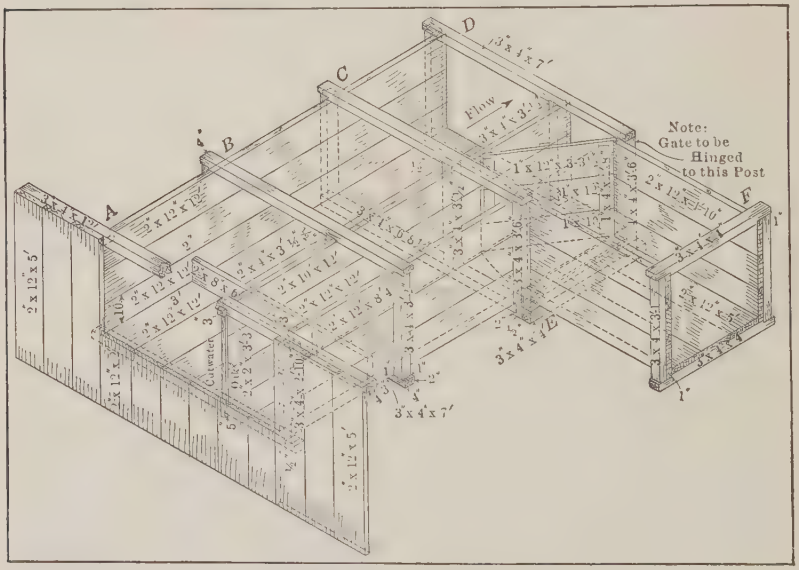


Fig. 74.—Design for proportional division box.

The division box shown in Fig. 74[1] is based on the principle that water flows over a weir crest in volumes proportionate to its length providing certain conditions are complied with. These are (*a*) that the velocity of water above the weir and before it is influenced by it is quite low; (*b*) that the crest board be set far enough downstream in the flume so as to insure complete side contractions; (*c*) that the influence of backwater, if any, be uniform across the box; and (*d*) that the crest be kept level.

[1] Scobey, Fred C., "Gate Structures for Irrigation Canals," *U. S. Dept. Agr., Bull.* 115.

The division of water by means of such boxes can best be described by an example. At a certain box delivering water to John Smith there are 84 shares including Smith's yet to be served. The width of the water channel is 60 inches which is reduced to a net width of 58 inches by deducting the width of the division board. Mr. Smith has 17 shares of stock and the width of the crest serving his ditch would therefore be found by the following proportion.

Smith's crest in inches: 58 = 17:84 = 11.74 inches.

The Improved Venturi Flume.—This device was developed at the hydraulic laboratory at Fort Collins, Colo., and may be used for the measurement of irrigation channels of all capacities from one-half second-foot to several hundred second-feet. It consists of (1) a converging portion with a level floor; (2) a throat or contracted section having a floor that slopes downward; and (3) a diverging section with a floor sloping upward. The side walls are all vertical. A plan and vertical elevation of one of these devices having a total capacity of about 4 second-feet is shown in Fig. 75.

The greatest difficulty with most measuring devices lies in maintaining the unchanging surroundings that are necessary for proper agreement between the laboratory calibration and later field measurements. Both the weir and the submerged orifice are subject to silt deposits which change the contraction conditions and are also subject to large correction, in many cases, for the velocity of approach in the stream. As a device using the well-known principles discovered by the Italian hydraulician, Venturi, it would appear that the discharge would be determined by consideration of the difference in readings of two gages, one in a known area of water prism above the throat and the other at the throat. By actual calibration, however, it was determined that only the first reading is necessary for all conditions of free flow and up to a point where the elevation of the surface below the crest is less than that above the crest by only 25 per cent of the depth on the crest. The formula representing the law of flow is the most unsatisfactory part of the device. As is noticed this involves an exponent in which one of the factors is itself modified by a fractional exponent, thus:

$$Q = 4WH_a^{1.522W^{0.026}} \qquad (1)$$

which may be expressed for logarithmic solution by the formula:

$$\log Q = \log 4 + \log W + \left(1.522W^{0.026}\right) \log H_a \qquad (2)$$

in which the term $1.522W^{0.026}$ may be solved as $\log 1.522 + 0.026 \log W$.

Ha is the depth of water at a point two-thirds the distance upstream from the crest along the vertical wall of the converging section, the crest being the downstream end of this converging

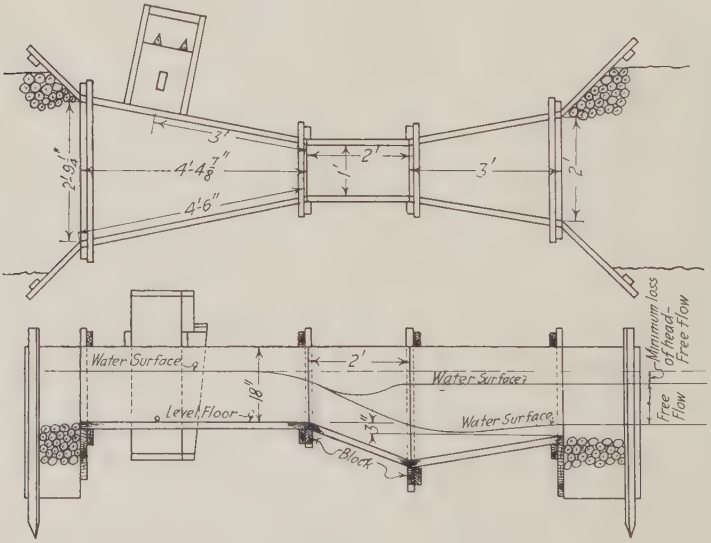


FIG. 75.—One-foot improved Venturi flume.

section or the point of entry to the throat. Knowing this depth *Ha* in feet and the *W* of the throat in feet the discharge *Q* may be calculated from the formula.

This law was based on 152 tests of flumes with throat widths of 1 to 8 feet. The discharges derived from the formula when compared with actual volumetric measurements gave an error of 1 per cent. in 47 per cent. of all the tests, an error of 2 per cent. in 78 per cent. of the tests and an error of 3 per cent. in 88 per cent. of the tests.

A well is attached to the converging section as shown in Fig.75 and water enters this well from the canal or ditch through a small tube. A metal float rests on the water surface within the well and is connected with an integrating instrument shown in Plate III which indicates the discharge in second-feet or acre-feet according to the requirements of the water user.

The improved Venturi flume according to Parshall possesses the following advantages:

1. It is accurate enough for practical purposes.
2. It operates successfully with small loss of head, this loss being about one-fourth that for weirs.
3. Sand or silt in the water does not affect its operation or the accuracy of its record.
4. Its range of capacity extends over wide limits.
5. It may be built of wood, concrete or metal the latter being used for small sizes.

According to Scobey, it possesses another advantage, in that, owing to the hydraulic jump feature, the regimen of flow is quickly established.

Time-flow Method.—When a constant stream of water whose volume has been measured is turned into a lateral ditch or pipe, the simplest, cheapest and most accurate means of ascertaining the quantity delivered to each irrigator who uses it in turn is to keep a record of the time of flow to each. For lack of a better term the writer has called this the time-flow measurement.

Current Meter-rating Station.—One of the best equipped meter-rating stations in this country is located at Fort Collins, Colo., and forms part of the hydraulic laboratory built and operated cooperatively by the Agricultural College of Colorado and the Bureau of Public Roads of the U. S. Department of Agriculture.

The rating channel shown in part in *A* and *B* of Plate IV consists of reinforced concrete 3 1/2 feet deep and 5 feet wide with an operating length of 200 feet without grade. On the top of the sides of the channel mine rails weighing 20 pounds to the yard are fastened. These should have been about double the weight. Two views of the electric driven car are shown in Plate IV. The car as equipped in *A* is used for a rigid connection of the meter rod and *B* shows the same car on which a wooden frame work is placed for the purpose of rating meters suspended by a cable.

Various car speeds are maintained throughout the trial runs. The car is driven by direct current at 125 volts, while the power circuit to the laboratory is 440 volts alternating current. By means of a field rheostat the current supplied to the car can be regulated in voltage thus changing its speed. This with an arrangement of gear ratios provides any speed of car within the required limits.

The record of the rating is made automatically. A chronograph records the time in seconds, distance and revolutions of the meter turbine. *A* Plate IV shows the chronograph, *B* the clock with seconds pendulum and *C* electric contact of seconds pendulum connected with relay and chronograph.

Water flowing under normal conditions in any ditch or canal has a relatively high velocity at the center and a slow velocity at either side and along the bottom. In order to obtain the average velocity it is necessary to determine the speed of the water at various points or in various sections. The usual practice is to select a suitable part of a straight channel having a smooth and uniform section in which the velocity of the water is slow rather than fast. An ideal velocity is about 2 feet per second. A plank or timber may be placed across the channel, and the width of the water surface marked thereon in feet. Beginning at station zero as shown on the plank, ascertain the depth and mean velocity at station 0.25, and afterward at stations 1, 2, 3, etc. The depth in feet at stations 1, 2, 3, etc., multiplied by the mean velocity in feet per second, will give the flow for that particular station in cubic feet per second and the sum of all these products will represent the discharge of the ditch, with the exception of what flows through the small areas at each side. The small area between stations zero and 0.5 is considered as a triangle and its discharge computed. The fractional part of a station at the other edge of the water surface is similarly treated, thus completing the total discharge.

In determining the mean velocity of any vertical section the integration method is recommended for small ditches and streams. This consists in moving the meter vertically from just below the surface of the water to the bottom of the ditch and back again to the surface, making one or more complete trips from the surface to the bottom and back to the surface, taking note of the

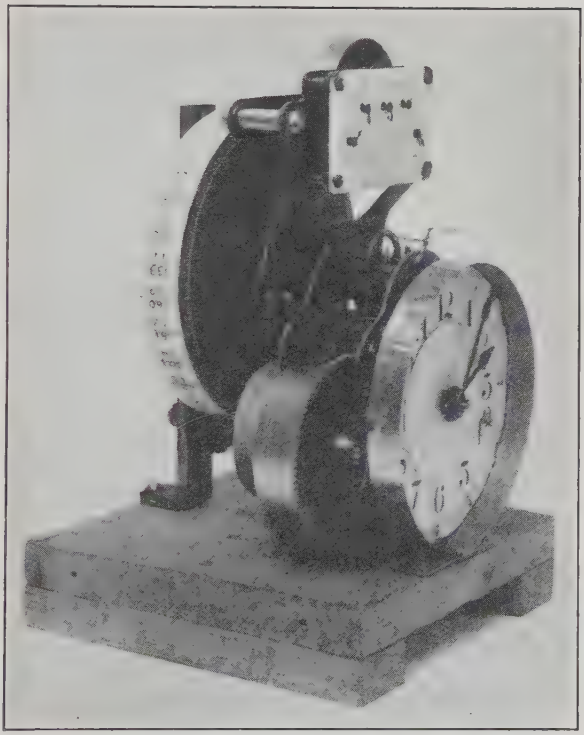


FIG. A.—Recorder for improved Venturi flume..

(*Facing page 184.*)

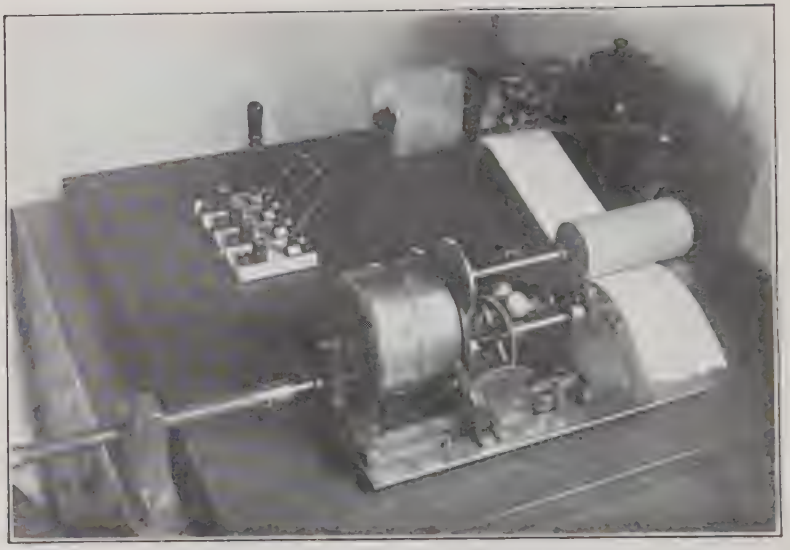


Fig. C.

Fig. D.—Laboratory clock with second's pendulum electrically connected to clevonograph.

Fig. E.—Electric contact of second's pendulum connected with clay and clevonograph.

time by a stop-watch, and counting the revolutions of the meter in the entire period. In using this method, care should be exercised to move the meter very slowly and uniformly through the water, so as to secure the average of the different velocities in any vertical section.

Until recently the current meters on the market have not been well adapted to the integration method. They likewise have other defects which impair their usefulness and accuracy in measuring velocities of water in motion. It was with the object of remedying some of these defects that E. J. Hoff, Mechanical Engineer of the U. S. Department of Agriculture, undertook the

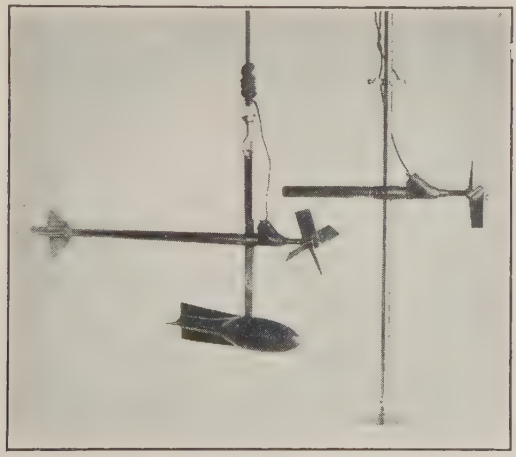


FIG. 76.—The Hoff current meter.

design of what is known as the "Hoff Current Meter" shown in outline in Fig. 76. This instrument is a general-purpose meter but is especially well adapted to the integration method because stream lines from the direction of 90 degrees more or less to the axis of the meter do not affect rotation.

Some of its other good features are its small volume and accurately prepared form which reduce to a minimum stream flow interference. The form of the propeller secures maximum action and minimum reaction from stream forces, and being made of rubber having a specific gravity nearly equal to that of water, instrumental friction is all but eliminated, rotation is accurately

controlled by stream velocity and reliable meter movements begin at low velocities.

The meter is convenient to operate and to keep in good working order. Its few parts are conveniently accessible and easily inspected and adjusted. Its small size and form cause little disturbance when inserted in flowing water and this in turn creates a favorable condition for an accurate gaging performed with little labor and in a short time.

The meter is actuated by the component of forward stream forces. Currents approaching the meter at angles between 60 and 100 degrees exert no influence in its rotation.

In brief, the Hoff meter is efficient in that it is sensitive, has little friction and indicates good meter action by its rating curve. It is accurate in that it will record nearly perfect velocity determinations.

34. The Conveyance of Water.[1]—Water in a stream or reservoir is of potential value only. It must be conveyed in artificial channels or pipes to the place of use, be this use irrigation, power, or municipal supply. The type of conduit—a general term applying to both open channels and pipes—must be determined from a consideration of a great many factors. Principal of these are: topography, cost, life, risk, expediency, and, to a very great extent, the necessary capacity. Since the ultimate object of all conduits is the conveyance of definite quantities of water and since all conduits of the same dimensions and grade do not carry the same quantity of water, a proper understanding of the relative capacities of all conduits must be reached before it is possible to make conclusions as to any one conduit.

Capacity.—In any conduit, natural or artificial, the capacity is the product of the cross-sectional area of the water prism and the mean velocity of the water; that is $Q = AV$ where Q is the quantity in cubic feet per second,—usually referred to in the West as "second-feet;" A is the area of the water prism in square feet and V is the mean velocity of the water in feet per second at the

[1] This article has been prepared by Fred C. Scobey, of the Division of Agricultural Engineering, U. S. Dept. of Agr., the author of the following Government publications on the subject: *Bull.* 194, "Flow of Water in Irrigation Channels;" *Bull.* 376, "Flow of Water in Wood Stave Pipe;" *Bull.* 852, "Flow of Water in Concrete Pipe."

section where A is taken. The area A is, of course, quite definite and tangible, but the velocity V is a variable depending on many factors such as the slope or rate of fall of the conduit, the size of the conduit, the shape, and, to an unbelievable extent, on the nature of the surface in contact with the water.

Conduits are of two general types, open channels and pipes. A tunnel is an open channel when the water surface is exposed to the air, and takes the characteristics of a pipe as it becomes a pressure tunnel, *i.e.*, when the water prism occupies the whole tunnel section. Water appears to follow a different law of flow in a pipe from that in an open channel. In the latter there is a distinct cycloidal motion as the water rolls along the sides and bottom. The surface, however, although slightly retarded by the friction with the air does not take this characteristic cycloidal motion. The water prism in a pipe, on the other hand, is in contact with the same type of surface throughout its perimeter and this rolling, cycloidal motion takes place at all points of contact. The extent of this difference in the manner of flow is most noticeable in the use of coloring matter or salt for timing the velocity of the water. In a pipe the color or salt stays in a more or less compact body while in an open channel, no matter how smooth the sides, the color or salt drags out to such an extent that its usefulness as a means of measuring velocity is greatly impaired.

For some 40 years the best known and most used formula for open channels is that attributed to Kutter and Ganguillet. This formula, generally called "Kutter's," as given herewith indicates the complicated nature of the variation of the mean velocity.

$$V = \left\{ \frac{\frac{1.811}{n} + 41.66 + \frac{0.00281}{s}}{1 + \left[41.66 + \frac{0.00281}{s} \right] \frac{n}{\sqrt{R}}} \right\} \sqrt{Rs} = CR^{0.5} s^{0.5} \qquad (1)$$

In this formula in addition to the mean velocity V there are s, the slope or gradient in feet per foot of length of channel; R the *hydraulic radius*, measured by the area of the water prism divided by the length of the *wetted perimeter* P in feet; or $R = A/P$ and n the "coefficient of retardation," varying from about 0.011 for the smoothest of channels in commercial service to about 0.070

or more for sluggish canals and rivers very much choked with rushes, moss, stumps and so on. The proper values of n to assume will be taken up later in the discussion of the various kinds of conduits. The complicated fraction in the Kutter formula evaluates into C of the original Chezy formula—a constant no longer.

While there are still many engineers who use the Kutter formula for the flow of water in pipes as well as in open channels, it has become quite generally recognized that Kutter's formula should be confined in its application to open channels since such conduits were the only ones contributing basic data for the derivation of the formula. The laws of flow in pipes have the general form:

$$H = Kd^xV^z \tag{2}$$

The mathematical operations of these "exponential" formulas are handled by logarithms thus:

$$\log H = \log K + x \log d + z \log V \tag{3}$$

Where H is the fall or "loss of head" of the hydraulic gradient in feet per thousand feet of pipe, d is the diameter of the pipe in inches; V is the mean velocity of water in feet per second as before; K is a constant for a given kind of pipe; x is an exponent ranging from -1.16 to -1.25 in various kinds of pipe and z is an exponent ranging from 1.70 to 2.00. The proper values for general use will be given in the following discussion of each type of pipe.

The main characteristics of the principal open-channel types are given below. The capacity is discussed in terms of Kutter's n in the formula given.

Earthen Canals and Ditches.—By far the most common channel for the conveyance of irrigation water is the ditch excavated in earth. It is usually the cheapest in first cost but requires attention in order to maintain its capacity. As the materials are more or less porous there is a constant seepage or loss of water throughout the length of the channel. This may be as low as 5 or 10 per cent. where silted waters are carried and may amount to 40 or 50 per cent. for long canals on gravelly hillsides. In some cases the whole flow has been absorbed by porous material before the irrigable land is reached. Velocities usually range from 2 to 3 feet per second. Unusual conditions may necessitate

as low a velocity as 1.5 for "sugar" sands with clear water or may permit a velocity of 5 to 6 feet in hard clays or shales. To determine the velocity that may be expected and also the capacity, use a value of $n = 0.0225$ in Kutter's formula for fair-sized ditches and canals that will be well maintained and a value of $n = 0.025$ for small farm ditches. Unusual conditions will give values of $n = 0.016$ for smooth clays without vegetable growths and values of $n = 0.027$ to 0.030 for ditches in gravelly loam where the loam will wash away, leaving a gravel bedding. These values also apply to ditches moderately choked with moss growths, cat-tails or other water grasses.

Concrete Linings.—Where water is valuable, seepage losses relatively high, or there is a liability of destructive washouts, earthen channels are often lined with concrete. This may be a coat of from 1 to 2 inches of "gunite" shot directly on the prepared inner surface of the channel by means of the "cement gun" or it may be a poured lining of concrete slabs from 2 to 4 or 5 inches thick. Gunite linings reinforced with small-mesh chicken wire cost from 7 to 15 cents per square foot while poured slabs cost from about 10 to 20 cents or more per square foot. The type and dimensions of concrete linings are dependent on so many things that they should be used only under the guidance of an engineer familiar with such work. For the determination of the capacity use a value of $n = 0.014$ for concrete poured in slabs and surface floated, while gunite linings may be designed for a value of $n = 0.017$. Experiments on linings show values of n as favorable as 0.012, where an exceptionally smooth coat is obtained, and values as unfavorable as 0.018 or more where moss, insect larvae or other roughening agencies change the original coating For all practical purposes any velocity is permissible though from 5 to 10 feet per second is most common.

Flumes.—Where depressions are to be crossed or the hillside is so steep that there is insufficient room for a canal, then the conduit may be placed in a pressure pipe following the surface of the ground or it may take the form of a flume—an open channel following the grade line. In designing a flume practically no attention is paid to the elevation of the flume bottom, all computations being made for the surface-water line. As the velocity is usually increased as the water enters the flume from a canal, it is essential

that the computation show a fall in the water surface at the flume entrance sufficient to provide the increased velocity. This is called the "velocity head." Also about 10 per cent. of this head should be allowed in addition to care for the "entry loss" as the water prism swings round the corners of the flume entrance. At the outlet a part of the velocity head may be recovered but the amount is problematical and recovery has not been counted upon much in the past. Velocities are usually from 4 to 10 feet per second. Beyond 10 feet the surface location becomes very difficult to prophesy as great waves splash from side to side and excessive freeboard is necessary to keep the water in the flume.

Wood-box Flumes.—All of the early construction in the West had recourse to the simple trestle structure supporting a rectangular box of planed or unplaned lumber, with the cracks battened with thin boards. Curves were turned by a series of angular bends. This type of structure is now used only where lumber is very cheap or the project very much in need of funds. Such flumes have a life of from 7 to 15 or more years. They should be designed for a value of $n = 0.015$ for mountain canyons or 0.014 for unplaned straight flumes. For perfectly straight, short reaches this type of flume will always be much in favor for "chute drops"—wasteways from canals—as velocities up to 40 feet or more per second are used. Wood-box flumes are often installed in the original construction with the idea of replacing with concrete at a later date when the project has recovered from the initial heavy costs.

Wood-stave Flumes.—The use of staves for the construction of pipe naturally suggested their use for flumes. A gradual development has taken place until now the practice is quite standard. Creosoted staves are placed in circular cradles until about five-eighths of the circle is reached. Only the half circle is considered in computing the capacity. Across the top "spreader ties" are dapped to receive the edges of the flume and rods extend round the flume bottom, snugging the staves together by bolts through the spreader pieces. This type of flume is sturdy, free from leakage, requires no battens, conforms to fairly sharp curvature and is so uniform in its interior that a minimum of freeboard is required. If a concrete or treated substructure is used a long life may be expected, probably in excess of 30 years

though there is little experience available to determine what life should be assigned, in economic studies. This type of flume is essentially a flume body supported by cradles. For carrying capacity use a value of $n = 0.012$ for fairly straight flumes or 0.013 for flumes following the usual mountain canyon. Velocities up to 12 feet per second will follow a reasonably sinuous alignment without slopping over the edge.

Steel Flumes.—The use of galvanized-steel sheets is a development of the last 15 years. At first a relatively low capacity was a detrimental feature but the present standardized practice offers a product for which an acceptable capacity is quite definitely known. Overlapping sheets are crimped and held together by countersunk rods that form a comparatively smooth interior. The flume body is built as a semicircle, the carrier rods passing through metal pieces bolted to longitudinal stringers which parallel the flume near the top edges. Spreaders are used, every 2 or 3 feet, to maintain the top width of the channel. When water is in the flume the semicircle sags at the bottom to a form approximating the hydrostatic catenary curve. For this reason there should be no braces or sash pieces under the center of the flume, leaving a free space of from 6 to 12 inches, depending on the flume size. If the flume sags until it touches any obstruction a leak will take place. The inlet and outlet ends, usually set in concrete, should be given the sagged form rather than the semicircle, to prevent leakage as the flume is filled. To obtain a long life periodic painting is recommended, especially where an abrasive is carried by the water. The capacity may be computed with a value of $n = 0.012$ for straight, unpainted flumes with an increase up to about 0.015 for a very sinuous painted flume. Velocities are usually held within a range of from 4 to 10 feet but with a deep freeboard higher velocities may be attained. The designer is cautioned against manufacturers' capacity tables that ignore the necessary freeboard and make computations for a flume flowing full to the extreme edge of the steel. This is of course utterly impossible and proper correction for freeboard must be made.

Concrete Flumes.—Following other construction concrete is now accepted as one material to be considered when permanent structures are to be built. Like concrete linings there are several

types of concrete flume. Concrete lends itself, in particular, to "bench flumes;" that is, flumes without trestle support but resting directly on a bench cut in the hillside. A trestle or other type of high flume may be made of concrete throughout but a concrete box is seldom or never superimposed on a timber substructure. Some ot the most pleasing structures have been made of gunite, shot against wood forms; some from the inside and some from the outside. When shot from the inside the surface must be carefully treated or an excessively rough interior will result. Another method of box construction is to precast sections for the sides, finally uniting the units by casting pilasters outside the joints. For a trestle flume the bottom is also precast but for a bench flume the bottom is poured after the side units are in place; the reinforcing rods being cast in the side units with extensions for the floor ties. The last type is the continuous monolithic construction, the concrete being poured into forms in the usual way. For precast sides curvature is usually cared for by using one of a few predetermined standard curves. Where a concrete flume is to replace an old flume and a minimum of time may be allowed for the water to be turned out of service, then the precast type may be used to advantage as the units may be made beforehand in a few selected spots, taken by truck or small train to the proper place along the line and rapidly assembled after the old structure is torn down.

Pipes.—In irrigation practice pipes are used in three quite distinctive ways; first, for the purpose of crossing depressions too high or too rough for a flume structure; second, for conveying water through highly developed agricultural land; third, for conveying water from a pumping plant to a higher elevation where the water is released into open channels that command the irrigated area. For the first and third uses the pipe is generally laid on top of the ground but in the second use one of the main objects is the conservation of land area so the pipe is laid beneath the cultivated top soil. Of course, in places where appearance is of moment every endeavor is made to conceal the pipe. There are three generally used materials of construction; concrete, wood staves and steel.

Concrete Pipe.—In California alone there are several thousand miles of jointed concrete pipe, mostly without steel reinforcement.

These pipes range in size from 6 up to 36 inches in diameter, for the most part of units 2 feet in length cemented together as they are laid in a trench. In irrigation use, the larger sizes are usually made by monolithic, continuous construction. Up to a few years ago concrete, without steel reinforcement, was used throughout Southern California with a well-understood limit of about 20 feet for the pressure heads under which the pipe line was to be operated. Better choice of materials, better proportioning and better tamping methods have brought about a product that may be used under far greater heads than would have been thought possible a few years ago. Concrete pipe, like other products of this material, is considered as of extreme long life. Weaknesses to which concrete is susceptible usually cause failure very quickly. Hence, such pipe either last a very long time or else fail almost immediately. Pipes laid in the early eighties still show original surface marks made during construction.

The capacity of concrete pipe depends greatly upon the methods and care of manufacture. This type of pipe is the roughest of pipe materials if carelessly made and laid with poor joints. It classes with the smoothest when cast in oiled forms and allowed to take its permanent set while held within rigid molds. The best of concrete pipe has a capacity nearly 50 per cent. above that of the poorest. However, it should be stated that the finest grade of concrete pipe is very costly to manufacture and is probably prohibitive for irrigation use. Its use is largely confined to municipal water supply conduits. In formula 2 (p. 188) the exponent x has been determined to be -1.25 and the exponent z to be 2.00. The constant K ranges from 14 for old California pipe lines where joints were not carefully cleared of all excess mortar, down to 6.7 for the best of pipe mentioned above. The usual well-made pipe under present practice will have a value of about 10.4 or less.

Wood-stave Pipe.—Where water is to be conveyed in pipe lines having pressure heads in excess of about 20 feet, a pipe made of an assembled length of machined wood staves has long been a favorite, especially for the larger sizes. The irrigation syphon pipe, carrying water between open canal sections across a depression, is quite generally of stave construction. Occasionally such a syphon is made of concrete pipe at both ends—until the pressure

head exceeds 20 to 30 feet. This plan uses concrete at its best—under light heads and does not subject the stave pipe to a very unfavorable condition—a pressure head that is insufficient to maintain a saturated condition in the staves.

For irrigation and power use in the west, the California redwood and the Douglas fir are used exclusively.

The redwood has a long life without chemical treatment. The fir is usually considered to have a life of from 15 to 20 years without treatment, but when the staves are subjected to impregnation of creosote under pressure there is no experience to tell what the life will be; undoubtedly more than 35 years. The stave pipe yields the best services where conditions are such that the line may at all times be kept full of water and where the line may be laid above ground so that all parts of the shell are under constant inspection. It appears especially important that a stave line should not be buried—where this is necessary—until after it has been filled with water and the initial leakage stopped by a judicious combination of band tightening and stave swelling.

The capacity of stave-pipe lines is now quite definitely established. There appears to be little or no depreciation in capacity with age, such as we have in metal lines. In formula 2 (p. 188) the exponent x may be taken as -1.17 and exponent z as 1.8 with $K = 7.68$. This formula will yield results that are usually within 10 per cent. of the computations even for pipes of mature age.

Steel Pipe.—The use of metal has not been so extensive in irrigation practice as that of either wood or concrete. However, some projects have many miles of light "stove-pipe" sheet-metal pipes, and steel is nearly always used where excessive pressure heads are involved, especially for the larger sizes of pipe. While stave pipe have been constructed 15 feet in diameter under light pressures, the limiting diameter is very much less where pressure heads of several hundred feet are involved. In power construction the stave pipe is much used for the low-pressure heads of the penstocks and tapering-diameter steel pipes for the higher heads. For irrigation and municipal use concrete is sometimes used for the lower pressure ends and steel for the high heads. Concrete pipe has not been used in this country to any material extent for power penstocks. Steel pipes are made under many processes—

chiefly differing in the joints, the oldest and most used type being riveted in both belting and longitudinal joints. Newer processes tend toward a smoother interior and hence a higher capacity. To the best of our present knowledge all metal pipes depreciate in capacity as their age increases. This depreciation is a chemical process that takes place much faster in some waters than in others. Also the rate of depreciation is greatly influenced by the condition of the interior protective coating. The capacity of new steel lines may be determined by formula 2 (p. 188) by using for the exponent x a value of -1.17 and a value for exponent z of 1.85 while K varies from about 7.1 for new smooth pipe to about 9.3 for riveted pipe 10 years old.

35. Evaporation from Water Surfaces.—With the development of the West, increasing quantities of water are stored in reservoirs for subsequent use in the production of crops, in the creation of hydraulic power and in furnishing water to urban populations. Since a part of the water so stored is evaporated from the surface of each reservoir, it is of importance particularly to the engineering profession to ascertain the extent of this loss and the factors which cause it. The loss of water in irrigation canals is small in proportion to their flow but the same cannot be said of shallow rivers in wide stream beds or of swamps and marshes in which native plants grow in shallow water. A knowledge of the rate and extent of evaporation from a water surface with free exposure to the air also furnishes a standard of comparison and a means of measuring evaporation from soils—a subject of so much interest to the irrigation farmer.

The equipment used in ascertaining evaporation from a water surface usually consists in a hookgage, standard rain gage and a galvanized metal pan or tank, but apart from the material of the container no standards have been adopted, at least until recently, regarding the size, form or manner of installing the tank. One of the first, if not the first, evaporation tanks installed in the West was at the Agricultural College at Fort Collins, Colo., in 1887. This was a cube of 3 feet in each dimension. Owing, however, to the difficulty and cost of making tanks of this form the usual type has been circular in form from 2 to 6 feet in diameter and from 2 to 3 feet in depth set in the ground so that not more than a 3-inch rim projected above ground and filled

with water up to within about 3 inches of the top of the vessel. For years records were taken from evaporation tanks located on the grounds of the Agricultural Colleges and Universities, and also at the hydraulic works of municipalities and corporations throughout the West, and use was made of them in estimating evaporation from storage reservoirs and other bodies of water. During this period, uncertainty existed as to the proper coefficient, if any, to apply to the tank records in order to adapt them to reservoir conditions. In 1915, the author tried to obtain first-hand information on this subject and for this and other purposes recommended that a field laboratory be established by the Irrigation Division of the U. S. Department of Agriculture to carry on investigations on the water requirements of crops, evaporation and other kindred subjects. Such a laboratory was established at the outskirts of Denver, Colo., at an elevation of 5,346 feet. The assistant of the author, R. B. Sleight, had charge of the work during 1915 and 1916 and his assistant Harry F. Blaney in 1917.

The evaporation equipment consisted of pans or tanks ranging from 1 to 12 feet in diameter installed in the earth with 3 inches above ground and a complete set of meteorological instruments. The results of these investigations may be briefly summarized from the progress report published in Vol. X, No. 5, of the *Journal of Agricultural Research*, July 30, 1917.

For the period Mar. 6 to Nov. 13, 1916 the relative evaporation in percentages, assuming the 12-foot tank to be 100, is given for each tank in the following table. The tanks held 3 feet of

TABLE No. 29

Diameter of tank, feet	Evaporation in percentage	Diameter of tank, feet	Evaporation in percentage
1	155	7	106.0
2	128	8	103.0
3	123	9	101.0
4	118	10	100.5
5	113	11	100.2
6	109	12	100.0

water, were inserted 2.75 feet in the ground and were similarly exposed.

Ralph L. Parshall, Irrigation Engineer, Division of Agricultural Engineering, U. S. Department of Agriculture, undertook in the late summer and fall of 1924, to determine the evaporation from the supply reservoir of the Fort Collins, Colo., hydraulic laboratory. This reservoir is circular in plan having a bottom diameter of 72 feet, a top diameter of 80 feet and a water depth of 6.5 feet. It was lined with concrete several years prior and all the joints of the original lining where dug out and refilled with asphaltum pitch. After the surface of the lining was cleaned and scraped, it received two heavy coats of an impervious mixture composed chiefly of asphaltum. After this treatment, it is believed the reservoir was water tight. In comparing the evaporation from the reservoir with that from a tank 3 feet square and 3 feet deep at some distance away for the period Oct. 1 to Oct. 31, inclusive, it was found that the reservoir lost 3.804 inches while the tank lost 3.288 inches. This is not in accord with the results found at the Denver laboratory. When it is considered, however, that the influencing factors of temperature of the water and wind movement were different at the reservoir and tank, the results do not seem faulty. The wind movement across the reservoir was 1,518 miles and that at the tank 1,035 miles during the test. The temperature of the water in the reservoir was also from 3 to 12°F. higher than it was in the tank. It is not possible at this stage of the investigation to evaluate correctly the influence of these two factors on evaporation but the results when modified by an estimated amount agree closely with the results obtained at the Denver field laboratory.

Mr. Parshall has designed and installed at the Fort Collins hydraulic laboratory an optical evaporimeter, the essential features of which are an evaporation pan, a high-grade speculum mirror, a high-power telescope and a system of cross-bars and pivotal points. By this equipment it is possible to measure losses of water by evaporation in amounts much less than the 1/100 part of an inch. With its use Mr. Parshall has developed a tentative formula for evaporation under still air conditions, which appears on page 199.

TABLE NO. 30

Locality	Years of records	C	Mean monthly evaporation in inches											
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Bozeman, Mont., class A tank, 4 feet in diameter	1916 to 1924	0.68				2.64	5.40	6.64	8.33	7.33	4.58	2.39		
Biggs, Calif., tank 6 feet in diameter	1913 to 1919	0.89				4.47	6.97	9.30	9.55	7.92	5.87			
Burns, Ore., tank 6 feet in diameter	1914 to 1919	0.89				4.16	6.18	7.70	9.26	7.80	5.12			
Dickinson, N. Dak., tanks 8 and 6 feet in diameter	1907 to 1920	0.91				3.75	5.02	6.12	7.11	6.40	4.27			
Garden City, Kan., tank 8 feet in diameter	1908 to 1916	0.94				6.49	8.71	9.62	10.74	8.81	7.51			
Garden City, Kan., tank 6 feet in diameter	1917 to 1924	0.89				6.12	7.81	9.91	11.09	10.11	7.86			
Nephi, Utah, tank 8 feet in diameter	1907 to 1919	0.94				4.59	6.61	9.00	9.65	9.23	6.39			
Walla Walla, Wash., class A tank, 4 feet in diameter	1918 to 1923	0.65			2.56	3.96	5.31	7.58	9.87	8.61	5.23	2.43		
Fort Collins, Colo., tank 3 by 3 by 3 feet	1918 to 1924	0.80	1.39	1.52	2.61	4.22	4.89	5.59	5.73	5.31	4.36	3.29	1.57	1.28
Lincoln, Neb., class A tank, 4 feet in diameter	1918 to 1924	0.68				5.56	6.91	8.19	9.10	8.47	6.88	5.10		
Lincoln, Neb., tank 7 feet, 6 inches in diameter	1918 to 1924	0.93				4.03	4.78	5.84	6.36	5.85	4.63	3.26		
Mesa, Ariz., class A tank, 4 feet in diameter	1923 to 1924	0.68	3.43	4.49	6.41	8.11	11.70	12.25	10.06	7.83	6.28	5.45	3.24	2.43
Willcox, Ariz., class A tank, 4 feet in diameter	1923 to 1924	0.68	4.50	4.38	7.12	9.64	12.86	13.18	10.64	9.97	9.61	8.01	5.09	3.27

$$E = 0.08(t_s - t_a + 3)^{2/3}(E_s - E_d)$$

Where E = the evaporation in inches per 24 hours.

t_s = the temperature of the water surface in degrees Fahrenheit.

t_a = the temperature of the air 1 inch above water surface.

E_s = the vapor pressure of water in inches of mercury.

E_d = the vapor pressures of dew point of the air in inches of mercury.

In the course of a few months Mr Parshall hopes to derive a formula adapted to general conditions.

Making use of the results obtained at the Denver field laboratory from 1915 to 1917, inclusive, and the more recent results of investigations now in progress at the Ford Collins hydraulic laboratory, it is possible to modify the evaporation records taken from pans and tanks in different parts of the West in such a way that they will represent more nearly reservoir conditions. In Table No. 30 some of these records are given in the form of monthly means for the number of years of record and also the value of the coefficient C by which the figures representing the mean monthly evaporation in inches of each series of records should be multiplied in order to arrive at approximate reservoir conditions.

INFLUENCE OF ALTITUDE ON EVAPORATION

The observations by Mr. Frank Adams of the Office of Experiment Stations U. S. Dept. Agri. during the summer of 1905, on the eastern slope of Mount Whitney, California, to determine the effect of altitude on the evaporation from a water surface originally reported in *Engineering News*, Vol. 58, No. 12, show, in general, that the evaporation decreases as the altitude increases but that it is due to the altitude, and consequent reduction in atmospheric pressure is not definitely established.

The evaporation curve in the accompanying diagram shows how the evaporation varies with the altitude. The evaporation increases as the altitude decreases except at the first and last station, but on account of the difference in exposure at these two stations, the results obtained are not strictly comparable with the remaining data. When, however, the average air-temperature and water-surface temperature curves are plotted with the evapo-

ration curve (Fig. 77), it is evident that the altitude is only one of the factors which cause the difference in evaporation. Both the water- and the air-temperature curves follow in a general way the variation in the evaporation curve and in the case of the air-temperature curve the agreement is quite close. The water temperature being due to the temperature of the air, the variation in the water temperature is not so great and consequently the agreement is not so close. The water-temperature curve is not drawn through the point for the station at the top of Mount

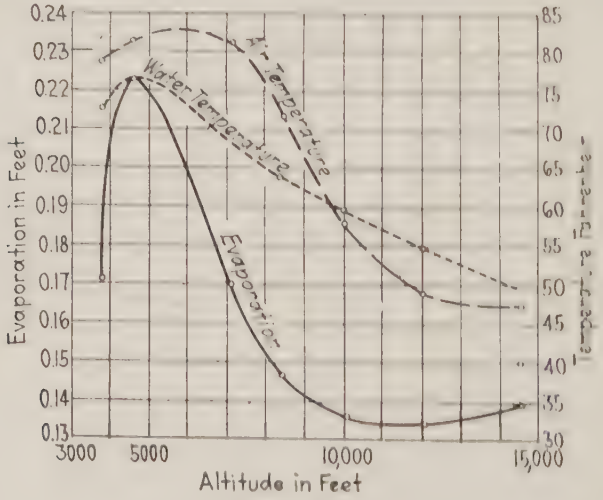


FIG. 77.

Whitney because the original notes show that the data from which the point was computed are inconsistent. The similarity between the temperature and evaporation curves is so close, however, that this point may be disregarded.

In these comparisons, neither the wind nor the difference in vapor pressure has been taken into account. Both of these factors are known materially to affect the amount of evaporation, and until some plan is perfected for eliminating them as well as the temperature from the results of the observations, it will be impossible to determine how much of the change in the evaporation was actually due to the change in the altitude.

36. Evaporation from Irrigated Soils. Under the direction of the author and in direct charge of Prof. S. H. Beckett, of the University of California, experiments were carried on at Davis, Calif., during 1924, to determine the relation between the amount of water evaporated from a water surface and that from saturated and nearly saturated soils under similar climatic and physical conditions. The equipment consisted of 5 galvanized tanks, 2

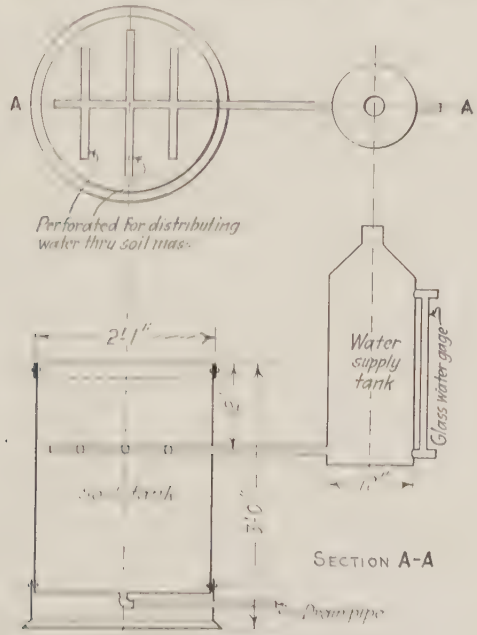


Fig. 78.—Soil tank for determination of evaporation losses from saturated soil.

feet 1 inch in diameter and 3 feet deep, one being filled with water and the other four with Yolo fine sandy loam. Tank 1 was filled with water to within 1 inch of the top and a hook gage fastened to the tank indicated this level. At 8 a.m. and 5 p.m. each day sufficient measured water was added to bring the water surface to its original position.

Tanks 2 and 3 were connected with a supply tank by means of a small pipe which distributed the water 12 inches below the surface in the soil tank as shown in Fig. 78. The tanks were then filled with equal weights of loam, and water was added until it

began to appear on the surface of the soil. The soil in the tanks was allowed 4 days to become stable when the top of each soil surface was carefully leveled and a mark placed on the water-glass gage on an exact level with the leveled surface. At 8 a.m. and 5 p.m. each day sufficient measured water was added to the supply tank to bring the water level to the mark on the gage. During the day the water receded about 1/4 inch below the mark but raised slightly above it at night.

Tanks 4 and 5 were treated in the same manner as tanks 2 and 3, with this exception. The water level was maintained 1 inch below the surface. Observations of the water level standing in a small hole in the soil showed the level to stand at 1 inch below the soil surface during the night and at an average depth of 1 1/4 inches during the day.

The weekly results of a 9-weeks test are given in Table No. 31.

A comparison was made at the Denver field laboratory in 1916 between the evaporation from a water surface and that from different soil and river-bed materials maintained under a varying depth to water table. Table No. 32 gives the results obtained with the use of Cherry Creek sand and Table No. 33 those from the use of a fine sandy loam found on the site of the laboratory. All tanks were 1.96 feet in diameter.

TABLE No. 31

Dates	From free water surface, Tank 1, inches	With water level standing at the surface of soil		Average, inches	With water level 1 inch below soil surface		Average, inches
		Tank 2, inches	Tank 3, inches		Tank 4, inches	Tank 5, inches	
Aug. 2 to 9.....	**2.780**	2.517	2.345	**2.431**	2.372	2.255	**2.313**
Aug. 9 to 16....	**2.483**	2.158	2.138	**2.148**	2.069	2.046	**2.053**
Aug. 16 to 23...	**2.104**	1.923	1.902	**1.912**	1.903	1.794	**1.848**
Aug. 23 to 30...	**2.581**	2.066	2.300	**2.183**	1.996	1.975	**1.986**
Aug. 30 to Sept. 6.....	**2.300**	2.078	1.914	**1.996**	2.005	1.830	**1.918**
Sept. 6 to 13....	**2.675**	2.072	2.277	**2.175**	2.084	1.970	**2.027**
Sept. 13 to 20..	**2.549**	1.973	2.133	**2.053**	2.216	2.053	**2.135**
Sept. 20 to 27...	**2.193**	1.877	2.017	**1.947**	1.986	1.922	**1.954**
Sept. 27 to Oct. 3	**1.925**	1.421	1.537	**1.479**	1.539	1.401	**1.470**
Total loss....	**21.590**	.....	.....	**18.324**	.....	.....	**17.704**

TABLE NO. 32

Period ending[1]	Actual depth of water evaporated, inches					
	Evaporation from water surface, Tank 2 (2 feet diameter and 5 feet deep)	Water table below the sand surface				
		Degrees (saturation)	3 inches	6 inches	10 1/2 inches	24 inches
Aug. 4	1.01	0.45	0.62	0.67	0.50	0.19
9	1.12	1.23	1.07	0.80	0.74	0.15
12	0.85	0.75	0.90	0.80	0.69	0.18
15	0.69	0.40	0.35	0.32	0.28	0.04
17	0.54	0.68	0.34	0.29	0.21	0.04
29	3.54	2.51	2.54	2.42	2.22	0.80
Sept. 12	4.44	3.14	2.71	2.62	2.47	0.34
25	2.83	2.34	2.16	2.06	1.82	0.25
29	0.91	0.46	0.42	0.40	0.36	0.12
Oct. 4	1.23	1.06	0.69	0.67	0.63	0.00
10	0.99	0.51	0.54	0.54	0.50	0.00
16	0.88	1.04	0.62	0.62	0.50	0.16
Total	18.93	14.57	13.06	12.21	10.92	2.27
Percentage[2]	100.0	77.0	69.0	64.5	57.7	11.3

[1] The period began on July 31, 1916.
[2] Water surface taken as 100 per cent.

TABLE NO. 33

Period ending[1]	Actual depth of water evaporated, inches						
	Evaporation from water surface of Tank 2 (2 feet in diameter)	Water table below the soil surface					
		4 inches	16 inches	28 inches	38 inches	43 inches	50 1/2 inches
Aug. 30	3.84	2.98	2.69	2.19	1.23	0.24	0.19
Sept. 15	4.77	4.37	4.09	3.12	1.98	0.37	0.32
25	2.10	1.81	1.67	1.44	0.30	0.16	0.16
29	0.91	1.04	0.84	0.69	0.43	0.11	0.16
Oct. 4	1.23	1.14	0.97	0.58	0.30	0.10	0.10
Total	12.85	11.34	10.26	8.02	4.24	0.98	0.93
Percentage[2]	100.0	88.2	79.8	62.4	33.0	7.63	7.24

[1] The period began on Aug. 17, 1916.
[2] Water surface taken as 100 per cent.

Other materials from the beds of the Rio Grande and Arkansas River were also tested at the Denver field laboratory, and the mean of these two gave a percentage of evaporation of 73 where the water table was 3 inches below the surface and 65 where it was 12 inches below the surface, as compared with a water surface which was taken at 100 per cent.

In 1916, somewhat similar experiments were carried on at Twin Falls, Idaho, under the direction of the author with Prof. M. R. Lewis in charge. The evaporation from a water surface contained in a tank 3 feet in diameter and 18 inches deep at the end of each week and that from the average of two tanks of the same size filled with a medium clay loam is given in Table No. 34.

TABLE NO. 34

Week ending	Evaporation from water surface, inches	Evaporation from saturated soil, inches
May 27, 1916		
June 8	1.50	2.20
10	1.79	2.23
17	1.68	2.60
24	1.73	2.22
July 1	1.81	2.59
8	1.66	2.38
15	2.06	2.87
22	1.67	2.64
29	1.73	2.26
Aug. 5	1.79	2.64
12	1.69	2.00
19	1.73	2.05
26	1.56	1.88
Sept. 2	1.56	1.81
9	1.40	2.00
16	1.33	1.60
23	1.04	1.40
30	1.04	1.33
Oct. 7	0.53	0.66
14	0.46	0.56

In this experiment the evaporation from a saturated soil is higher than that from a water surface but this is probably due to the

fact that the water table was kept high so that one-half the surface was water and the other half soil.

In 1924, a series of experiments was carried on cooperatively by the U. S. Division of Agricultural Engineering, the Colorado Experiment Station and the State Engineer's Office to determine the evaporation from typical soils and river-bed material along the Arkansas River in Colorado. Sample No. 1 was an adobe soil from Patterson Hollow heavily charged with alkali. Sample No. 2 consisted of a fine, sandy loam fairly free from alkali, taken from the experimental plots of the American Beet Sugar Company. The remaining four samples were river-bed material taken at different points along the Arkansas River, *viz.*, at Rocky Ford, Avondale, Las Animas and Lamar. The work was in charge of Ralph L. Parshall who designed and installed a somewhat unique apparatus for measuring the evaporation. The equipment consisted of six sets of water-jacketed tanks, a set of meteorological instruments, a track, six auxiliary tanks and the weighing apparatus. This equipment is shown in Plate V.

The results of the experiments with the six kinds of material for each of the four months, from August to November inclusive, are given in Table No. 35. It will be noted that the evaporation is low from the sample of soil taken from Patterson Hollow on account of the large percentage of alkali which it contained, it being well established that evaporation under like conditions from alkali soils is much less than from similar soils which do not contain alkali.

TABLE NO. 35.—COMPARISON OF EVAPORATION LOSS FROM TEST MATERIALS AND A FREE WATER SURFACE

Material	Depth to water table, inches	August			September			October			November			
		Inches loss	Free water surface	Ratio	Inches loss	Free water surface	Ratio	Inches loss	Free water surface	Ratio	Inches loss	Free water surface	Ratio	Average ratio
Patterson Hollow..	4.26	1.764	10.38	17	1.572	8.14	19	1.301	6.53	20	0.741	3.70	20	19
Experimental plots	5.61	3.022	10.38	29	2.323	8.14	29	1.755	6.53	27	1.206	3.70	33	30
Rocky Ford.....	4.05	8.811	10.38	85	6.434	8.14	79	4.640	6.53	71	3.102	3.70	84	80
Avondale.....	3.79	8.710	10.38	84	6.349	8.14	78	4.525	6.53	69	2.884	3.70	78	77
Las Animas.....	4.07	6.515	10.38	63	3.851	8.14	47	3.384	6.53	52	2.538	3.70	69	58
Lamar.....	3.84	7.705	10.38	74	5.555	8.14	68	3.881	6.53	59	2.541	3.70	69	68

C. B. Ridgaway[1] found that 6 per cent. of alkali in soil retarded evaporation 43 per cent. when the water table was maintained 6 inches below the surface.

F. S. Harris and J. S. Robinson[2] demonstrated the effect of soluble salts in the soil in decreasing evaporation. Their results are shown graphically in Fig. 79.

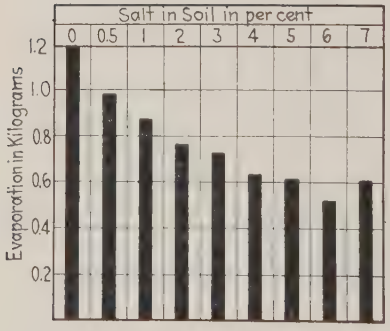


FIG. 79.—Evaporation from Greenville loam containing different quantities of common salt. (NaCL.)

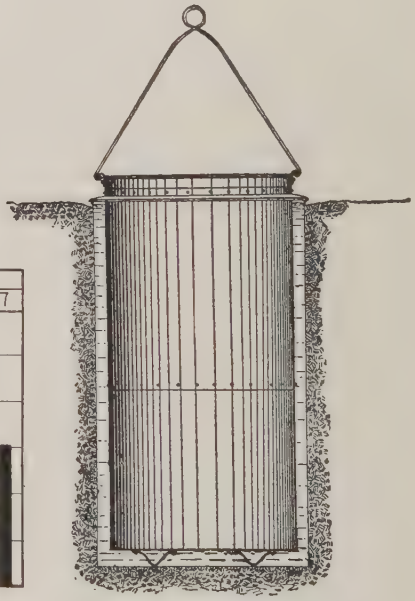


FIG. 80.—Design of tank used in evaporation experiments.

The evaporation from the fine, sandy loam taken from the experimental plots is also low but this can be accounted for by a low water table in August and the presence of some alkali. The four tanks of river-bed material agree fairly well in the amounts evaporated and are in general accord with other data cited in this article.

A large number of experiments were carried on by the author in the period 1905 to 1914 with the object of determining among

[1] See *Bull.* 52, *Wyo. Exp. Station.*

[2] *Jour. of Agr. Research*, Vol. vii, No. 10.

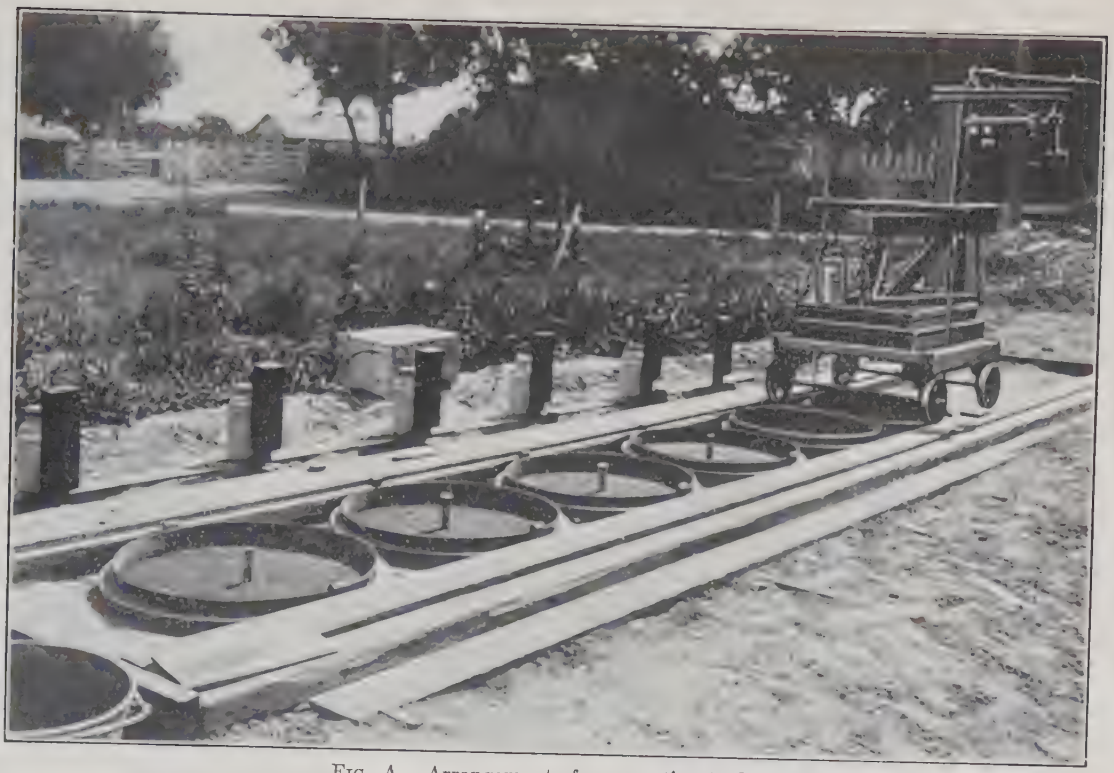


FIG. A.—Arrangement of evaporation tanks.

(*Facing page 206*).

FIG. B.—Meterological station.

FIG. C.—Lifting device mounted on platform.

other things the rate of evaporation from soils and some of the main influencing factors. The type of tank used for this purpose is shown in Fig. 80. These investigations demonstrated that the same factors which influenced the rate of evaporation from a water surface were also applicable to soils. In the case

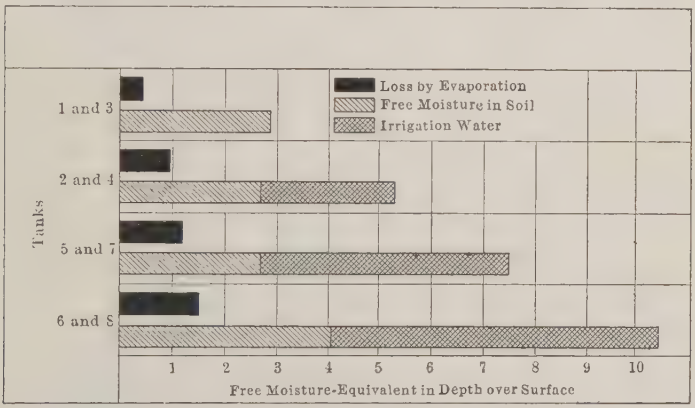


FIG. 81.—Diagram showing the initial amount of free moisture in the soil, the amount added, and the loss by evaporation, July 27 to Aug. 5, 1907, at Riverside, Cal.

of evaporation from soils, however, the governing factor is not the temperature of the soil and air, the movement of wind, or the humidity of the atmosphere, but the percentage of moisture in the top layer of soil. This is illustrated in Fig. 81 and also in Table No. 36.

TABLE NO. 36.—EVAPORATION FROM SOIL AND WATER

Kind of soil and percentage of free water	Mean temperature taken morning, noon and evening in degrees Fahrenheit					Weekly evaporation	
	Air in shade	Soil in shade	Soil in sun	Moist soil	Surface of water	Soil, inches	Water, inches
Sandy loam—saturated ...	71	76	95	83	77	1.75	1.88
Sandy loam—17.5	76	78	106	..	80	1.33	1.94
Sandy loam—11.9	76	78	106	..	80	1.13	1.94
Sandy loam— 8.9	76	78	108	..	80	0.88	1.94
Sandy loam— 4.8	76	78	108	..	80	0.25	1.94

The fact that a wet surface soil evaporates much more water than a dry one is of far reaching importance in agriculture. In the Missouri River basin a large part of the annual precipitation occurs in the form of showers of soft snow and rain from April to July and much of this is evaporated from wet soil surfaces. Again every time a field is irrigated by flooding, all of the surface becomes wet and the evaporation is heavy until the soil dries out. In cultivated crops much can be done to lessen evaporation by adopting suitable methods of wetting the soil. It is difficult

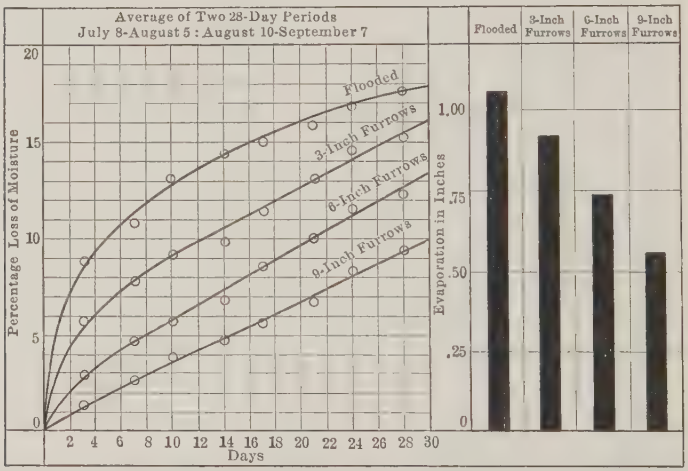


FIG. 82.—Average evaporation losses from tanks irrigated by flooding and with furrows of different depths at Reno, Nevada, July 8 to Aug. 5 and Aug. 10 to Sept. 7, 1909.

to determine by the use of tanks the evaporation losses under field conditions but Fig. 82 shows the results obtained from tanks at Reno, Nev., in 1909.

37. The Duty of Water in Irrigation.—Duty of water, or as it is sometimes termed, the irrigation requirement of arable lands, deals with water allotments for agricultural purposes and is more or less closely connected with the legal, administrative, engineering, economic, financial and agricultural phases of irrigation. Formerly, a plentiful water supply led to the use of lax methods in determining the rights of the users, and not infrequently excessive quantities were granted to individuals, asso-

ciations and corporations, but as water became more difficult to obtain and of higher value more care was exercised in defining the rights of each user. The need of revising many of the water rights which have been granted to over 20,000,000 acres and of correctly estimating the water requirements for 35,000,000 yet to be reclaimed conveys some idea of the scope and importance of this subject to the West.

During the past 75 years, various water units and forms of expression have been used to indicate the quantity of water required to irrigate an acre or other unit of land. The most commonly used units for the measurement of irrigation water have been defined in a previous article. The term "duty of water" originated in British India, where it signifies the amount of work which water may be expected to do or ought to do in irrigating crops, and is expressed in terms of the number of acres served by one unit of flowing water—the cubic foot per second.

On account of the quantity of water lost in transit, a determination of the duty of water made at the intake of a canal may differ widely from that made at the margin of each farm. This difference gives rise to the expression "intake duty" or "gross duty" which means the average duty under an entire canal system and includes all water lost in transit. "Net duty," or "delivered duty," means the amount of water applied to individual farms when measured at the margin of each.

The term "irrigation requirements of arable lands" is of more recent origin and means the quantity of water required per acre for the profitable production of crops adapted to the locality when the character of the soil, climate, and other physical and agricultural conditions are duly considered.

Under the heading "Low Efficiency of Irrigation Water" some facts are given regarding the loss of water suffered in its conveyance and field use. It is also true, however, that part of the water thus lost returns to natural water courses and is or may be reused. It follows that the duty of water or water requirements of the arable lands of a portion of any river basin may need modification when the entire basin is considered. This is particularly true of interstate and international rivers. In the case of the Colorado River by way of an example, the water used in irrigation in the states of the upper basin including parts of Wyoming, Colorado,

Utah and New Mexico does not represent the actual quantity of water used by each of these states since a considerable portion of the used water returns to the Colorado River and is subject to reuse in the states of the Lower Basin. The appropriate term "consumptive use of water" is used to express such conditions. The same expression properly applies to the quantity of water used in each natural subdivision of intrastate rivers. Thus Weber River in Utah flows in succession through four agricultural valleys with considerable return flow from each. Consequently, in arriving at the total potentialities of this river for irrigation purposes, the consumptive use of water in each valley is the one essential fact to be determined.

The water supply of the arid region being limited in volume, means must be taken to regulate its use. By the exercise of this control the flow of streams is apportioned to users of various kinds in accordance with a predetermined duty. It follows, therefore, that the duty of water when fixed by competent authority affects communities and enterprises, as well as individuals, and may affect states and nations.

All phases of this subject vitally concern the irrigator. He wishes to secure for his growing crops an adequate supply of water at the right time but in its use he may be governed wholly or in part by Federal statutes, state laws, state regulations, court decisions or water-right contracts which determine his right to divert and place limitations on the quantity of water which can be used for this purpose. It has, therefore, been considered best to preface this article with a brief outline of the broader aspects of the subject by discussing briefly the agencies and methods employed to place limitations on the quantity of water which can be used in irrigation.

1. *State Laws.*—The statutes of Idaho restrict the user to a maximum quantity of 1/50 of a second-foot per acre, but the courts of the state are empowered to grant more when necessary. This authority has been abused in a number of cases, since some decrees have granted as much as 1 second-foot for 10 acres. In the states of Wyoming, Nebraska, Oklahoma, New Mexico and South Dakota, the maximum limit is fixed by statute at 1/70 of a second-foot per acre, while in North Dakota it is 1/80 of a second-foot per acre. There is a similar limitation in Nevada

but the unit adopted is in acre-feet per acre, 3 acre-feet being the maximum.

To the writer, it seems unwise for any arid state to fix limitations of this kind. Outlined in another part of this article are some of the conditions which affect the duty of irrigation water. These conditions not only differ widely in different parts of the same state but change from year to year. The changes which time brings forth may be shown by citing a few cases. Some 25 years ago the irrigators of the Greeley district in northern Colorado were using a second-foot of water on 40 to 50 acres. In recent years the same quantity has served fully three times as much land with far better results when measured in crop yields. Furthermore, when the legislative assembly of Wyoming, in 1891, limited the duty throughout that state to 1 second-foot for each 70 acres it was actuated by the best of motives. Such a duty was then high. Now it is too low and the state is handicapped by having apportioned so large a volume of its public waters on the limit fixed by statute.

2. *State Control.*—The control exercised by a state may affect the duty of water in several ways. In many of the western states the apportionment, measurement and distribution of the appropriated waters are in charge of state officers, who are required to distribute the flow of streams in accordance with adjudicated rights. It oftens happens that by the exercise of good judgment in the performance of this duty, they can modify the defects or temper the harshness of court decisions. Sometimes the transfer of a little water for a short time from a superior to an inferior right may save a farmer's crops without inflicting any injury on his more fortunate neighbor who has a prior right. Such officers can be of so great service to the state in maintaining friendly relations among irrigators, in the prevention of waste of water, in the wise use of seepage and return waters and in securing the largest possible benefits from all available sources of supply, that the trend of public opinion favors giving them large discretionary powers in the exercise of their public duties.

Another form of state control is exercised by state land boards in examining and approving the duty of water on lands under Carey Act projects. In Idaho, for example, the prevailing duty

under such projects is 1 second-foot of water for each 80 acres of land, delivered at the head of the farmer's laterals.

State control is likewise exercised through special tribunals or water courts. In Wyoming the special tribunal is called the Board of Control and it is justly entitled to the highest praise for its efficiency. From the time this board was created in 1890 and organized in 1891, up to Jan. 1, 1914, it had adjudicated 12,500 rights to the use of water. These rights serve 1,510,000 acres. Considering the small number of its decisions that have been appealed, no other court can show so good a record.

H. W. Grunsky and the writer, when called upon to advise the ministry of British Columbia on matters pertaining to irrigation, recommended, among other things, a form of water license for the Province. This form of final license is in force at this writing and contains the following "terms and conditions:" (*a*) source of supply; (*b*) point of diversion; (*c*) the date from which the license shall take precedence; (*d*) the purpose for which the water is to be used; (*e*) the maximum quantity of water which may be used until lawfully altered, and the maximum quantity of water per annum which may be used on each acre actually irrigated in acre-feet; (*f*) the period of the year during which the water may be used; (*g*) the area and description of the land to which the water is appurtenant; (*h*) a concise description of the works; (*i*) a limitation of the water used per acre to that quantity which experience may hereafter determine to be necessary for the production of crops in the exercise of good husbandry, and (*j*) a reservation to the Province of the right to distribute water in rotation of time or otherwise for the purpose of securing the most economical use of water.

Some may regard these terms and conditions as unduly rigid and unfair to the irrigator. On the other hand, the belief is becoming quite general that the high value and scarcity of water and the demand which is being made on this natural resource will soon force the abandonment of lax laws and wasteful use affecting it.

3. *Court Decisions.*—Of the adjudicated rights, by far the largest number have been determined by district courts. Members of the legal profession generally favor this mode of procedure; and no valid objection can be raised to it, if only questions of

law are involved. Needless to state, however, the proper determination of a right to the use of water resembles that of the survey and location of a piece of land. It is based on the results of investigations pertaining to water and land measurements, the carrying capacities of ditches, seepage and return waters, character of the soil, water requirements of crops and other physical facts of like nature. Considering the question from this point of view it may well be doubted whether the ordinary law court is the best tribunal for such a purpose. In any event, grave mistakes have been made by such courts in the past. Some 20 years ago a part of the public waters of Colorado were adjudicated in a haphazard way with little or no effort to ascertain the physical facts. Many adjudications were based on the cross-sectional area of the ditch or canal without reference to its grade or the velocity of flow. In one case 33 second-feet of water were granted to 120 acres of land, and in another 31 second-feet to 200 acres. The owner of the ranch last referred to was recently offered $100,000 for the land and the water right, the latter being appraised at about $60,000.

It is but just to state that these decisions were rendered at a time when water possessed less value than it does today. Recent water decisions of the district courts are based on more accurate data, yet the tendency is still in the direction of granting a generous allowance, disregarding the public welfare and allowing too much latitude as to the period of time when the water can be used.

4. *Water-right Contracts.*—In general it may be stated that court decisions in allotting water supplies favor the water users at the expense of the public, while water-right contracts favor the company at the expense of the water user. Whether justly or unjustly, water-right contracts likewise exert a potent influence in restricting the quantity of water used in irrigation. While many companies and enterprises live up to their agreements, some delivering to consumers more water than the contracts called for, others, through stress of circumstances, seek to overcome the defects of a short water supply or unsafe structures, or both, by the insertion of one-sided agreements in the contracts. Most contracts of this kind stipulate that the company agrees to furnish a fixed quantity of water which must be

used on a definite area; and in case of water shortage at any time the amount available is to be prorated. Such provisions, when robbed of their legal phraseology, mean, as R. P. Teele of the U. S. Department of Agriculture states (*Annual Report O. E. S.*, 1908) "that the farmer takes what water he can get, for which he shall pay a flat rate per acre regardless of the quantity received."

Conditions Affecting Duty.—It has long been recognized that the amount of water required in irrigation differs widely on adjacent farms and in different localities and states. In briefly considering the causes of this the writer will not attempt to name all the conditions nor to designate the order in which they shall be presented.

1. *Value of Water.*—Where water is plentiful and cheap less care is certain to be taken in its use and less money expended in facilities for its conveyance and application. This accounts for the large amount of water per acre which is used in parts of central California and the relatively small amounts used in southern California. There are, of course, exceptions to this rule. In Florida, for example, water is both abundant and cheap but irrigation water is exceptionally high on account of the methods employed in its distribution and application, the cost of which varies from $50 to $250 per acre.

2. *Character of Soil and Subsoil.*—Porous soils, on account of the losses due to deep percolation, require much more water than retentive soils. This is illustrated in a marked degree by the use of water on the Reclamation Service project at Umatilla, Ore. On the "sand hill" area north of the town of Hermiston in particular, the soil contains 60 to 90 per cent. of coarse sand and gravel with little fine sand and an almost negligible amount of silt and clay. The irrigation season extends from Mar. 16 to Oct. 16—210 days—during which period contracts call for the delivery to the land of 2.8 acre-feet of water per acre. In 1912 the actual average delivery to the entire project was 9.7 acre-feet per acre. On the more porous portions it is considered necessary to irrigate alfalfa three or four times for each cutting. One grower with 7 acres irrigated five times for the first crop, and six times for each of the following three cuttings, making 23 irrigations for the season.

This project may also be cited for demonstrating what can be done to lessen the excessive use of water on such soils. By the use of larger heads in narrow, short border strips, a better preparation of the surface and delivering water in rotation the average duty in 1919 was reduced to 5.63 acre-feet per acre with 83 per cent. of the land irrigated in alfalfa.

3. *Climate.*—The rain which falls during the crop-growing season and to a less extent the annual precipitation have a marked effect on crop production and the use of irrigation water. In one sense all irrigation water is supplementary and the more rain which is absorbed by the soil, the less is the need for artificial supplies. It is likewise true that much of the rain which falls during the period of growth is wasted. The light shower may invigorate certain crops but it seldom adds anything to the moisture content of the soil, being too soon dissipated in vapor. It may actually deprive the soil of moisture by breaking down the dust mulch. Not only rainfall but temperature, the prevalence of high, warm winds, the rate of evaporation, and other climatic factors exert an influence on duty of water. The traveler in proceeding north from Arizona and New Mexico into the Province of British Columbia cannot but observe the heavy growth of timber which a light rainfall supports in the south-central part of this province. On account of the heavy evaporation in the southwestern states, the same rainfall there produces only desert plants.

4. *Proper Channels and Structures.*—In discussing the efficiency of irrigation water in Art. 31 the extent of the losses due to conducting water from place to place was pointed out. Until this waste is much reduced a high duty of water cannot be secured. Furthermore, since the small ditches made by the farmer waste a higher percentage of water there is much need for reducing this loss by careful and efficient construction and in some cases even to the extent of making them watertight. Much needless waste can likewise be saved by making shorter runs.

5. *Preparation of Land.*—Coupled with proper facilities for the carriage and distribution of the head used there is also required the careful preparation of each field. The attempt to irrigate land which has a rough, uneven surface, is frequently the cause of much waste of water, extra labor, small yields and eventually

damaged land. Not only thorough grading but thorough preparation of the seed-bed is essential.

6. *Diversified Farming.*—Cereals usually require to be watered one or more times during the period from the time the plants cover the ground until the grain is well "headed out." This represents a short period and the farmer who raises grain only has no further use of irrigation water for the balance of that season. On the other hand, in rotating grain with such crops as alfalfa, roots and fruit, these latter require late water and the use of the same flow is thus extended over a longer period and in consequence waters a large acreage.

7. *Time and Manner of Water Delivery.*—Water, as well as labor and time, can be saved and an economical duty secured where conditions are favorable by using large quantities of water for short periods of time. Irrigators in the northern tier of states have been slow to abandon the continual use of small heads. While this method has its advantages for the man having a large farm and crude irrigation appliances, it will be found profitable on the whole to rotate the supply with one's neighbors. Watering of crops is too important to be treated as a side issue. If one attempts to attend to other duties while water is running on his fields, only visiting the latter at long intervals, small yields are likely to result. It is better to see that the water is well distributed while it can be used. When the time of use has expired, the head gate is closed and the water flows on to the neighboring farm.

8. *Kind of Crops.*—The kind of crop, whether cultivated or uncultivated, and the length of season that it needs water have a direct bearing on the amount of water required. Winter grains seem to require the least irrigation water because they mature early and are able to make good use of the winter precipitation. Spring grains are not usually planted until some of the winter precipitation has been evaporated. Alfalfa, hay and pasture grasses grow luxuriantly through a long season and thus require the most water, it being found that such crops require about twice as much as grains.

9. *Fertility of the Soil.* Arid soils are deficient in vegetable matter and when this want is supplied by the right kind of rotation and by good farming generally, the soil becomes more

retentive of moisture and a unit of water will supply a larger area than is possible when the soil is in a raw state. What is true of humus and nitrogen is also true of other fertilizers. Generally speaking, the richer the soil and the better it is tilled, the less the water requirements for any one crop.

10. *Manner of Paying for Water.*—Paying for water by the season on an acreage basis tends to lower the efficiency of the water. As has been pointed out elsewhere, the water user under such a contract is given no chance to reduce his water bill by the exercise of economy. On the other hand, the practice of paying only for what water one receives is invariably followed by an economical use.

11. *Method of Applying Water.*—It is customary to employ the services of engineers to design and construct canal systems but as a rule the farmer receives no technical assistance in planning and building a proper system of irrigation for his farm. As a result farm ditches and fields are not well located, the method of applying water may not be suited to the soil or topography, much labor is needlessly expended in irrigating and much water wasted by deep percolation, evaporation and run-off.

12. *Legal Restrictions.*—The effect of these on duty of water has already been considered in discussing the limitations imposed by statutory, regulatory and judicial means.

Investigating Duty of Water.—A knowledge of the service or duty which water performs is necessary in all irrigated regions. This fact was early recognized in the development of the arid West. In 1892, the Colorado Experiment Station published a bulletin on this subject which gave the results of investigations made by Professor Carpenter. Two years later the writer began similar investigations. It was not, however, until Congress in 1898 appropriated money for irrigation investigations that a study of duty of water became general throughout the West. An urgent demand existed at that time for more information concerning the quantities of water used and required in irrigation. This information was needed by courts in determining water rights, by state officers in apportioning water supplies, by engineers in planning the capacities of canals and in estimating the areas of land which they would serve, by the managers of canal companies in drawing up water-right contracts, and by

those who used the water on their farms. Studies of this kind were continued for several years and the collected data proved of lasting benefit since they resulted in the framing of wise legislation and in the adoption of sound public policies in relation to water during a formative stage of irrigation development in this country. True, the results obtained have been criticised by agriculturists and others, who contend that too little attention was paid to the character of the soil and subsoil and to the kind of crops grown. Such critics overlooked the fact that the investigations as first planned were intended to supply information regarding the legal, administrative and engineering features of irrigation rather than the agricultural. Besides, the funds available were too small to permit a thorough study of the subject in all its phases. At that time it was infinitely better to ascertain the general average duty over 100,000 acres than to spend the same amount of money in more detailed studies on a 40-acre tract.

Both land and water measurements were made by men familiar with this class of work. The weir and rating flume were the most commonly used devices for measuring water. To secure a continuous record of flow, recording registers were imported from France until the demand for such instruments was pressing enough to induce American firms to make them. At first the work was quite generally confined to making a continuous measurement of the quantities of water which flowed through the intakes of the main canals but later the flow through laterals and farmers' ditches was measured. These measurements indicated a large transmission loss which took place between the main intake and the farmer's head gates, and efforts were made to ascertain the extent of these losses.

The writer was one of the first to apply different quantities of water to experimental plats in order to determine the effect of water on crop production. This work is still carried on in various parts of the West and bids fair to throw considerable light on the proper amount of water to apply to the different crops.

A plan of investigation which combined the plat and the large area was devised by Don H. Bark, irrigation engineer in charge of irrigation investigations in Idaho. Mr. Bark's

TABLE NO. 37

Crop	Season	Number of tracts	April		May	June	July	August	September		Total for season
			1 to 15	16 to 30					1 to 15	16 to 30	
Alfalfa	1910	15	0.0600	0.0210	0.5540	0.7390	0.6530	0.6070	0.0650	.....	2.6990
Grain	1910	31	.....	.....	0.3210	0.6000	0.5460	0.0780	.....	.....	1.5450
Alfalfa	1911	13	.....	0.0350	0.4930	0.2930	0.9130	0.6970	0.2480	.....	2.6790
Grain	1911	30	.....	.....	0.0270	0.6540	0.4780	0.0100	.....	.....	1.1690
Alfalfa	1912	11	.....	.....	0.4910	0.5030	0.6210	0.6080	0.0380	.....	2.2610
Grain	1912	25	.....	.....	.....	0.9420	0.6550	0.0460	.....	.....	1.6430
Alfalfa	1913	13	.....	.....	0.8627	0.2284	0.7422	0.3854	0.0175	.....	2.2362
Grain	1913	33	.....	0.0392	0.2062	0.5434	0.5941	0.2268	.....	.....	1.6097
Average	....	..	0.0075	0.0119	0.3693	0.5628	0.6504	0.3323	0.0460	.....	1.9802
Per cent. of total	....	..	0.38	0.60	18.65	28.42	32.85	16.78	2.32	.....	100.00

plan consists in dividing a typical cropped field into three parts. The owner applies to one part in one or more irrigations that quantity of water which in his judgment, will produce the largest yield. Mr. Bark's assistant applies by the same method a larger amount to the second and a smaller amount to the third part. By means of weirs the amount of water applied as well as the run-off is carefully measured. The yield on each subdivision is determined at harvest time and by comparing the quantity of water applied with the yield, a fairly accurate conclusion may be drawn as to the proper duty of water for that soil and crop. A large number of such experiments have been financed in southern Idaho by funds obtained from the state and the U. S. Department of Agriculture.

A summary of the quantities of water applied in acre-feet per acre for each month of the growing season on 171 tracts of selected alfalfa and grain fields during a 4-year period on medium clay and sandy loam soils of southern Idaho is given in Table No. 37.

Other results of duty of water experiments made in different localities of the West will be found under the general heading of Irrigation of Staple Crops.

Water Requirements of Crops.—This expression when used in its most restricted sense means the weight of water absorbed by a plant during its growth to the weight of dry matter produced. In determining this ratio the plants are usually grown in pots or tanks in order to eliminate as far as practicable the use of water for purposes other than that needed by the plant. Messrs. Briggs and Shantz of the U. S. Department of Agriculture used pots holding 115 kilos of soil and each pot was provided with a tight-fitting cover with an opening for the plant, the space around each stem being sealed with wax. Measured quantities of water were added at stated periods in order to maintain a uniform moisture content in the soil of each pot. A summary of water requirements of crops based upon the means of different varieties as obtained by these investigators at Akron, Colo., is given in Table No. 38.

In reference to the ratios given in Table No. 38 it should be noted that they are relative rather than actual since a number of factors affect the water requirement of crops. Temperature, evaporation, humidity, soil moisture content and soil fertility

all exert more or less influence on the quantity of water required by plants.

TABLE No. 38

Crop	Ratio of water requirement to dry matter	Relative water requirement compared with wheat	Crop	Ratio of water requirement to dry matter	Relative water requirement compared with wheat
Alfalfa	1,068	211	Wheat	507	100
Canada field pea	800	158	Potato	448	88
Artemisia (native)	765	151	Rape	441	87
Spring rye	724	143	Sugar beet	377	74
Sweet clover	709	140	Corn	369	73
Oats	614	122	Weeds	322	63
Buckwheat	578	114	Sorghum	306	60
Barley	539	106	Millet	275	54

In seeking to determine not only the seasonal water requirement of standard crops but also the need for water during each stage of growth, the author has used water-jacketed tanks having the annular space between the outer and inner tank filled with water. This equipment facilitates the weighing of the inner tank containing the soil and plants at daily or weekly intervals. The general arrangement is shown in Plate VI.

38. Delivery of Water.[1]—The final test of the success of every irrigation project is the quality of the service rendered to irrigators in the matter of water delivery. Adequate water-delivery service can be nothing less than the reasonably prompt giving to each irrigator the full share of water to which he is entitled and at such time and at such rate of flow as the crops to be irrigated require. If one crop is mainly irrigated the problem is comparatively simple, but one-crop agriculture is not usual, except in districts of highly specialized crops. Small fruits and shallow-rooting annual field crops are usually quite sensitive to comparatively light drought, while such crops as alfalfa, and to a less

[1] Prepared by WELLS A. HUTCHINS, Associate Irrigation Economist, Division of Agricultural Engineering, U. S. Dept. Agr.

extent orchards, on deep soil, have more elastic irrigation requirements. It is obvious, therefore, that a plan of water distribution must usually take account of diversified plantings scattered over an entire project, and that such a plan to be most effective must be directed toward the highest possible production of crops.

Plan of Water Delivery.—Three important methods of delivering water to irrigators have been developed on the irrigation projects of the West, namely, continuous delivery, rotation delivery, and demand delivery. Each of these plans has its good and its weak points. One plan, for example, under a given set of conditions, might be most desirable for the irrigators, but most expensive to carry out, and least economical of water. Another plan, again, might be satisfactory from a different angle, yet impracticable to carry out. It has been found necessary on some irrigation systems to alter the method of delivery after some years of trial, but such changes have seldom been accomplished without considerable friction between management and water users and in many instances have been prohibited because of the great expense that would have been involved in enlarging ditches, pipe lines, and structures. It is quite important that the plan of delivery to be adopted on a new system be well thought out before the capacity of the system is determined upon.

The "head" or "stream," as it is called in various sections, which may be stated to be the flow of water delivered to an individual irrigator or group of irrigators, is one of the principal variables to be considered in connection with a plan of delivery. Other important elements are the time of delivery and the duration of the irrigation period.

Continuous Delivery.—Under the continuous-flow method, a water user receives, or is entitled to receive, an irrigation stream continuously throughout the irrigation season. The size of this stream may be definitely fixed—as, for instance, 5/8 miner's inch per acre—or may be a definite percentage of the entire flow of the ditch, based upon the relation of the irrigator's acreage or shares of stock to the total acreage or shares entitled to water from the ditch. The irrigator does not necessarily use his water constantly, but is entitled to call for it whenever he wants it. An obvious feature of this plan is the necessity for delivering very small heads of water. Continuous delivery is the rule on

many systems in the northwestern states and on some of the steeper slopes of the Sierra Nevada foothills in California.

Rotation Delivery.—Another plan involves the delivery of water in turn to various parts of a project, the heads delivered being larger than continuous heads owing to the fact that only a portion of the water users are receiving water at any one time. On some systems where continuous delivery is practised, groups of farmers taking water from the same lateral arrange to pool their several irrigation streams and to rotate the combined stream among themselves. For example, if A has 20 acres, B 30 acres, and C 40 acres, each being entitled to 1/2 inch per acre, they would rotate the total of 45 inches among themselves, giving the entire stream to A for 2 days, then to B for 3 days, to C for 4 days, and then back to A again for his 2-day turn. Some irrigation projects in the San Joaquin Valley of California and elsewhere deliver as much water as a user wants while the supply is abundant in the spring, and then rotate the water according to a more or less flexible schedule when the supply is no longer sufficient to give everybody all he wants. Rigid schedules are the rule on some systems, a number of which are in Utah, each tract being allotted a certain number of hours' run per acre with a standard irrigation stream, the turns coming at regular intervals through the season. Another plan is to vary the size of head and the hours' run per acre, the larger heads, of course, going with the shorter runs. In case of a break in the canal or other obstruction to the flow of water, the users whose turns occur while water is out of the ditch may lose those turns altogether, although in some places the more equitable plan is to cut down the time of all users proportionately until the normal schedule can be resumed. It is the experience of some irrigation managers that rotation schedules are difficult to enforce in those seasons when the water supply is overabundant or when storms occur during the irrigation season, simply because a strict rotation plan is not needed under such circumstances and demands for water are apt to be spasmodic then.

Demand Delivery.—A third plan of delivering water is on demand of the user. This method allows the user to ask for the size of head he wants, the time wanted, and the length of time the water is wanted. Necessarily on most irrigation systems appli-

cation for water must be made a certain length of time, ranging from 1 day to 5 or 6 days, before the water is wanted, although in a few cases small heads delivered under pressure are available immediately whenever needed.

The Delivery "Head."—The size of the delivery head or stream is of vital importance to an engineer in designing an irrigation system and to an irrigation manager in delivering the water. Extremes are to be discouraged wherever possible, not only because of the unavoidable waste of water that sometimes results, but because of the wasteful practices encouraged. Within the extremes, however, is a wide range of sizes of head from which a choice should be made that will best fit local conditions.

As stated above, very small heads are of necessity delivered under the continuous-flow plan of delivery owing to the fact that the entire water supply must be parceled out to all users at one time. In the northwestern states the continuous streams may be at the rate of 1/2 inch or more per acre, but rarely exceed 1 inch per acre. A man with less than 20 acres would therefore command an irrigation stream not over 20 inches in size and possibly as small as 10 inches, which would seldom permit of practicable use unless combined and rotated with a neighbor's stream. In some of the valleys of the northwestern states a head of 25 inches, or about 1/2 second-foot, is considered adequate for irrigation purposes, particularly where used in conjunction with the corrugation method of applying water, although those farmers who are able to obtain experience with larger heads are usually readily converted to their use. In certain instances as little as a single miner's inch has been used for furrow irrigation on 2- or 3-acre tracts, but such minute heads are decidedly out of the ordinary.

Rotation heads are larger, simply because such rotation head is equivalent to an aggregation of continuous streams. In the northwestern states even the rotation heads are relatively small, being usually 2 or 3 second-feet and seldom exceeding 5 or 6 second-feet. In California, however, although small rotation heads are delivered on some systems, heads as large as 15 second-feet are the rule on many enterprises and even from 20 to 30 second-feet on others. Where such heads are used, the land must needs be carefully prepared, preferably in checks or borders, else

the water cannot be controlled. With such practice a standard head of, say, 20 second-feet would be divided among 3 or 4 checks, which would be covered probably at the rate of 15 or 20 minutes to the acre. With light, porous soils, the entire head might be turned into one check at a time in order to force the water to the end of the check without undue absorption at the upper end.

Heads delivered under demand systems of delivery are usually subject to more or less variation in size at the option of the user, although a practical limitation exists in the size of laterals and to some extent in the number of demands on any single lateral. That is, if one user wishes water from a lateral, a small head might be out of the question because of the heavy transmission losses that would result, whereas if several users want small heads the aggregate of these heads would be more practical to carry in the lateral. The delivery of large heads is, of course, limited by the carrying capacity of the lateral.

It may be laid down as a general rule that the delivery head should be adequate for the successful irrigation of the user's land without unnecessary waste of water. It should be large enough, therefore, to reach the lower end of a check or furrow without resulting in unduly heavy losses through deep percolation of water at the upper end; but it should not be so large that it will rush over the ground and waste at the end of the field without penetrating the soil in quantities sufficient for proper plant growth. The proper size of head for any farm, therefore, will depend largely upon the soil and topography of the farm. Steep slopes require small heads, and level land requires larger heads; likewise, tight soils need small heads and porous soils larger ones. Sometimes the problem is to get the water over the ground; at other times, to get it into the ground.

Delivery Plans Compared.—Continuous delivery is used in many situations to which it is not suited and has, therefore, acquired the reputation of being a wasteful method of delivery. This imputation, however, is not entirely just, for there are certain limited circumstances under which this plan is the only effective means of accomplishing irrigation. For example, steep slopes on which larger heads would wash can be safely irrigated only with the very small streams; and impervious soils, in many

cases, cannot be irrigated at all except with very small streams applied for long periods of time. Under such circumstances, the water is oftentimes required almost constantly for farms of 20 acres or more. Likewise, such crops as rice require water continuously during most of the growing season, and truck and small fruits require it so often that even a small tract can be well served by having a small stream constantly. But outside of a narrow range of circumstances the plan of continuous delivery is not economical of water, and frequently requires an unduly large amount of the farmer's time and attention.

The rotation plan has grown up on many systems where the use of small heads would be wasteful of water and where a real necessity existed for conserving the water supply. This method has the advantage of providing larger heads than the continuous plan, but has the drawback that water is not available to the user at all times. A well-planned delivery schedule can overcome this drawback to a large extent by making the irrigation turns coincide as nearly as possible with the needs of the individual irrigator. In a one-crop country where the soils are fairly uniform in texture, the development of a satisfactory schedule is comparatively easy, but it is extremely difficult where crops are diversified and where soils are not uniform, and where these latter circumstances are extreme the rotation plan is not satisfactory and should if possible be supplanted by a scheme that will make water available more nearly when needed. An iron-bound rotation schedule that does not accomplish these results has little justification. In general, the rotation plan is superior to the continuous-flow plan in many sections of the West, but often requires great care in the preparation of the rotation schedule, with the best use of the water supply and the needs of the irrigator's crops kept always in mind.

Demand deliveries are obviously most satisfactory for the individual irrigator. This plan is best suited to deliveries from a reservoir or from a stream of fairly constant flow where the supply of water is in excess of the demand. The plan is not economical, however, unless demands on a single lateral are sufficiently well grouped in time to justify turning water into the lateral without unduly heavy transmission losses. This difficulty is overcome on some systems by withholding deliveries

until the demands accumulate to a certain point, but such practice might conceivably work hardship on an irrigator or group of irrigators by requiring them to wait a long time for water. In a well-settled district, however, applications for water are usually so well grouped that water can be delivered practically on demand without serious losses. It has been the experience on some projects that in the early years when the supply greatly exceeded the requirements of the sparsely settled lands, water could be delivered on demand of the users; then as the irrigated area and the total requirements increased, the supply no longer exceeded the demand and a rotation plan became necessary; and finally with close settlement of the land, and with greater knowledge on the part of the management and water users of the proper quantities of water needed by different crops and in different sections of the project, deliveries on demand again became possible with a higher utilization of the water supply and with a minimum of waste.

Delivery Force Required.—The first essential of a water delivery force in irrigation systems is, as previously pointed out, that it shall understand the needs of the water users. While it is almost always necessary that the ditch tenders charged with water delivery shall also patrol the canal system for breaks, make all ordinary repairs that can be attended to in connection with their other duties, and remove accumulations of trash and weeds from delivery structures, their duties in connection with water delivery should be paramount to maintenance and on large systems at least their water-delivery activities should be directed by a head water master not connected with the maintenance work of the system. An example of such division of duties is found on one of the largest irrigation systems in Idaho, where there is a superintendent of operation (including water delivery) and a superintendent of maintenance, both reporting independently to the general manager.

The ditch tender carries on his shoulders a large responsibility. He is in immediate charge of a number of miles of canal in which the flow of water requires delicate adjustment in order that it shall not break over the banks and cause serious damage. He comes in daily contact with the water users in his division and is often the only employee of the company or district whom the

water users consult with. Consequently the force of circumstances requires the ditch tender to be a buffer between water user and management, and if he cannot discharge his responsibilities without consequently losing his temper he is out of place in such employment. The ditch tender must possess an appreciable amount of tact, but must be capable of showing firmness in enforcing the rules of the organization. It is necessary that he shall have had some irrigation experience, or at least have capacity for learning much about irrigation before accepting such employment; and many managers will not employ for such duties a man without water-delivery or irrigation-farming experience. As the ditch tender is required to make notes and keep accurate records, his ability must extend to those accomplishments also.

The number of ditch tenders required to deliver water for a given area depends upon so many different conditions that no general rule can be laid down for arriving at the necessary force. The unit to which water is delivered—that is, whether delivery is made only out of the main canals of a system, or out of the main canals and main laterals only, or to every section of land, or to every separate ownership, etc.—doubtless has most to do with the size of force needed, for it directly involves the number of deliveries to be made by the management and the mileage of canals to be operated. Of great importance, however, are such factors as the close grouping of irrigated areas, the number and size of irrigated farms, plan of water delivery and care with which deliveries are made, character of topography of the country, travel facilities for ditch tenders, and, to a lesser extent, the character of crops, frequency of irrigation, and length of the irrigation season. Hence, for any given set of conditions, all of the important factors must be known and properly weighted before an accurate forecast may be made of the number of ditch tenders required. Under some organizations each ditch tender delivers water to an average of only a few hundred acres, while in others in which delivery is made to relatively large units the average exceeds 10,000 acres. Systems delivering to units of less than 160 acres can seldom undertake distribution of water to more than 3,000 or 4,000 acres of irrigated land per ditch tender unless circumstances are unusually favorable for a high degree of efficiency in

delivery work, and on many well-managed enterprises of this character the average is considerably less.

Control of Water.—An essential part of the operation of an irrigation system of any considerable size deriving its water supply from a single source, or from more than one source where the water is intermingled later in the same ditches, is the close control of the flow of water throughout the system. This control is frequently centered in one person, often the superintendent, and sometimes called the water dispatcher, who keeps his finger on the pulse at all times. In some cases he spends most of his time at a desk, although it is often possible to confine the desk work to a portion of the day only, generally either in the early morning before the ditch tenders start out on their daily rounds or in the late evening after they return to their stations, at which period this dispatcher gets in communication over the telephone with all ditch tenders, or on the larger systems with the division water masters, ascertains the situation, and gives orders covering the diversion and distribution of the water for the next 24 hours.

Close control of the water implies that the management, through the ditch tenders, shall have sole control of all delivery gates. In actual practice on some systems the water users are allowed to change the gates, either opening or closing them, and on certain systems may close their headgates when water is no longer wanted but are prevented by a lock from opening them beyond a set point. It is necessary, however, that a system have ample canal capacities and be well provided with spillways at strategic points if the users are to be allowed to turn back water not wanted, for serious damage may result if more water than the canals can carry is turned back into them.

Water Delivery Forms.—Forms used for making applications for water, reporting deliveries and keeping records are quite varied, both as to the operations they deal with and the detail they go into. The character of such forms is, of course, a matter for each organization to decide for itself in view of the detailed or only general information wanted, intricacies in handling deliveries, etc. But it may be stated as a general rule that forms required to be used by ditch tenders in the field should be as simple as possible while at the same time making it easy to report all essential information. Most calculations can be handled

more readily in the office by a person trained for such work than by a ditch tender on a canal bank, and unless it is imperative that results be known immediately, either for answering inquiries of water users or for other reasons, these results can best be left for office computation. The requirement that every report submitted by a ditch tender be signed and dated by himself is of great importance.

Forms for keeping permanent office records likewise should not be more elaborate than necessary. One large organization installed a system of records that required so much expense in keeping it up that its subsequent curtailment became necessary. A happy medium should be adopted that will keep all important information on water diversions and deliveries in readily available shape whenever access to the records is desired. The importance of keeping such records cannot be overemphasized, for they are invaluable for showing the development of the project, for use as evidence whenever necessary, and for providing accurate data on which to base extensions and improvements in service and other economies.

Construction and Operation of Small Laterals.—An important feature in the first construction of an irrigation system is the extent to which distributary laterals shall be built by the company or district; and in the subsequent operation of the system, the extent to which the management shall distribute the water. That is to say, a large percentage of the earlier enterprises constructed only the main canals, or main canals and main laterals, and left to the farmers the task of building connecting ditches, yet later found it desirable to take over and operate these connecting farmers' laterals. More recently a large percentage of newly constructed systems have included in their plans the building of laterals to relatively small farm units.

Construction.—The question of the first construction of small laterals is closely associated with the problems of the irrigated farm as discussed in the early part of this book. The plan of many of the earlier systems of which only the main canals and laterals were built by the organizers made it necessary for the new settlers to build laterals miles in length, which, taken in connection with their heavy duties in subduing the land, was often an onerous burden. One man might have this work to do

alone, or he might be aided by others who could also use the ditch. In any event, it involved considerable time and labor that could ill be spared from the manifold duties immediately on the farm.

On the other hand, where the farmers built these connecting laterals, the first cost of the main system was reduced accordingly and there was avoided the danger of building ditches that might lie unused for years. Constructing and paying interest on the capital invested in unused works is, of course, an economic waste. The proper policy in constructing these laterals, under any scheme of financing them, would be to build them no farther in advance of their actual use than can be reasonably worked out. The question of which party shall build them can be decided partly on the basis of the policy to be adopted in aiding farm settlement on the project, with due regard, of course, to the experiences of other projects on this matter.

Success in leaving the construction of small laterals to the irrigators has been varied. In some cases development has unquestionably been retarded; yet there are instances of rather complete construction of laterals in which settlement of farms has been quite slow. Such communities as the Union Colony in northern Colorado have handled lateral construction successfully, largely, it is thought, because of the homogeneous character of the people and their willingness to work together. Many of the pioneer Mormon colonies in Utah built their laterals and main canals as well by their own unaided efforts because of their singleness of purpose and their great capacity for industry. Furthermore, some of the most important districts in California, with populations far from homogeneous, developed their lateral systems by the individual efforts of the farmers, but the growth of these laterals took place over a long period of years and was not without serious financial difficulties. Apparently at the present time, when the capital investments in large irrigation works must be discharged more promptly if large irrigation construction is to continue, the necessity for rapid settlement of irrigation projects calls for a generous policy of constructing all necessary ditches to carry the water to the individual farm, whether or not additional financial aid be given in actually developing the farm.

Operation and Maintenance.—The operation and care of the small laterals, at least for a time after their construction, has

usually devolved upon the party building them. The Union Colony and others of the same type were as successful in operating their lateral systems as in building them, and for the same reasons. But very often local control has not been at all satisfactory, particularly in the absence of a formal organization of some sort, owing to the tendency of some users to let the others do most of the work, or to the inability of all users to get along harmoniously, or to racial and other deep-seated differences which generated distrust of neighbors and prevented a common understanding. The expense of caring for the small ditches is often less when handled by local users than by a central organization and necessitates a smaller cash outlay; but, on the other hand, the work is less apt to be thoroughly or uniformly done, especially after the irrigation season starts and the farmers are busy with other things, and on a large project the operation of such laterals may or may not be satisfactory to the management. The trend of affairs in this connection is indicated by the rather large number of farmers' laterals that have been taken over by the managements of various enterprises, seldom with compensation to the farmers, and due to the unsatisfactory state and frequently the inequitable cost of local operation.

Organizations for Control of Laterals.—To insure proper distribution of water and an equitable division of the cost of handling the same, as well as to accomplish the maintenance work that must always be done, some type of organization is practically essential except in cases where only a few users are concerned. For the larger laterals, an incorporated company is often advisable, for the legal standing it gives and for the privilege of issuing shares of stock which may be transferred readily in case of the sale of land or even, under some conditions, from one tract of land to another. For smaller laterals a contract signed by all users and recorded in the county records is satisfactorily used in many places. In irrigation districts in Washington and a few other states it is possible to form local improvement districts for the construction or improvement of laterals serving definite areas of land. Some state laws provide for the formation of organizations to handle the operation of laterals and particularly the measurement of water to the users.

Regulations Governing Water Delivery.—Most irrigation enterprises of any size have their rules and regulations for governing the distribution of water and the relations between the management and the water users. It is necessary, of course, that the proper regulations for each project be prepared with regard to the particular conditions present, but there are certain principles of regulation that with some variation are desirable for any well-managed system. The most important of these[1] may be outlined as follows:

1. The superintendent and the ditch tenders working under him should have sole control of all gates, checks, and turn-outs, and users should be prohibited from altering them without definite authority from the superintendent or ditch tender, of course excepting cases of emergency.

2. Every irrigator should be required to make written application for any water wanted, on blanks furnished by the management, the application to be handed to the ditch tender or sent directly to the central office of the system a sufficient number of days—usually 1 to 3—prior to the time water is needed. This enables the superintendent and ditch tenders to make necessary arrangements for getting the required flow in the various laterals.

3. Irrigators should be given ample notice of the time water is to be delivered and should be held responsible for being ready to receive it at the time set.

4. During time of water delivery ditch tenders should, wherever practicable, be required to be within ready call of the irrigators receiving water. This is especially necessary where comparatively large irrigating heads are being delivered because it frequently happens that for one cause or other the delivery must be temporarily or prematurely stopped, in which case the ditch tender should be on hand to care for the water turned back.

5. It is desirable, but not always practicable, that water users should make all complaints in writing. In justice to the users the rules should require that all complaints filed in writing shall be promptly investigated by the superintendent.

6. The rules should require ditch tenders to keep careful record, on suitable forms furnished by the management, of all deliveries made, such record to state the time of beginning and ending of each delivery,

[1] Prepared by Frank Adams, Professor of Irrigation Investigations, Univ. of Calif.

the size of head furnished, the acreage irrigated, and the crop watered. On some systems it has been found desirable to require irrigators to give written receipts, preferably in the ditch-tenders' record books, for deliveries made.

7. Ditch tenders should be given authority in the rules to prevent all avoidable waste from the irrigable fields. Where water is repeatedly wasted through excessive application the ditch tenders should be required to report the fact in writing to the superintendent, regardless of whether this waste is depriving some other user of water. Excessive application of water is of general injury through causing the rise of ground water, and irrigators should at the start be taught that they are entitled to no more water than the crops being irrigated require.

8. The rules should require all farm ditches to be of proper capacity to carry without undue waste the water delivered. They should also require that they be kept in good repair throughout the delivery season.

9. Authority should be given in the rules for placing locks on all turn-out gates when this is found necessary.

10. The superintendent should be given full authority to discontinue water delivery to any irrigator who wilfully and repeatedly disregards the established regulations of the system.

11. It is usually desirable to establish a definite irrigating season within which water will be available. In such cases the limits of the irrigation season should be stated in the rules. This should not mean that where feasible water is not to be run at other times. Sometimes it is very desirable that irrigation should occur during the winter months which are never included in a regular irrigation season, and where desirable, this should be encouraged. In the Southwest some irrigation systems usually carry water for 10 or 12 months of each year.

12. The rules should specify the duties of ditch tenders in the matter of patrol and care of canal banks and structures, and also in the matter of the reports to their superintendent and of their proper relations to irrigators.

39. Injurious Mineral Salts.[1]—Soils are constantly subjected to chemical and mechanical agencies which, among other things, render soluble parts of their mineral and vegetable ingredients. Abundant and frequent rains such as characterize the humid region penetrate the soil and carry much of the soluble materials into rivers, lakes and oceans. Vast areas designated as arid,

[1] The author is indebted to W. W. McLaughlin of the Division of Agricultural Engineering, U. S. Dept. of Agr. for many of the views expressed in this and the following article.

however, have insufficient rainfall to leach away the soluble salts of the soil, thus giving rise to the accumulation of these salts throughout the surface and subsoils frequently in menacing amounts. Many of the alluvial valleys of arid America at one time contained saline water lakes, or arms of the ocean, and the older soils of these valleys are in consequence alkaline. In some valleys and adjacent mountains, beds of salt have been deposited. Occasionally these salt beds are cut into by torrential streams which in flood overflow large areas with saline water. The waters of all streams used for irrigation contain dissolved mineral salts and the continued application of such water by irrigation in the absence of good underdrainage is another source of salts in the soil.

"Alkali," a term commonly given to all excess mineral salts, usually exists in the form of chlorides, sulphates, carbonates and nitrates of sodium, calcium, and magnesiun. Broadly speaking, the world over, alkali salts consist chiefly of sodium chloride (NaCl), common salt; sodium sulphate (Na_2SO_4), Glauber salt; and sodium carbonate (Na_2CO_3), sal soda. The latter is commonly spoken of as "black alkali" since it dissolves organic matter and thus gives the soil surface a dark color, while the other salts which are less harmful to plants, form a white crust on the soil and are hence classed as "white alkali."

The dry weight of a soil remains practically constant but the moisture content may and does vary over a wide range. It is for this reason that the alkali content of a soil is expressed as a percentage of the dry soil weight. However, this percentage seldom represents the concentration of alkali salts in the soil solution, and it is this solution of which the plant makes use. Thus, if a soil weighing 80 pounds per cubic foot contains 0.50 per cent. soluble salts and 25 per cent. of moisture, the soil solution would contain 2 per cent. of alkali, but if the moisture content were reduced to 12 1/2 per cent. the alkali concentration in the soil solution would be 4 per cent.

The maximum percentage of plant tolerance for alkali in the soil is only very generally determined, due probably very largely to the ever-changing moisture content and resulting alkali concentration. The tolerance depends upon the chemical nature of the alkali, kind of plant, type of soil, and composition of irrigation

water used. Young plants are more susceptible to alkali injury than older plants. Hilgard's limits of 0.1 per cent. sodium carbonate, 0.25 per cent. sodium chloride and 0.50 per cent. sodium sulphate observed for cereals in sandy loam soil are valuable as a general guide. In clay and other fine-textured soils, plants are injuriously affected with a less concentration of alkali than in coarser-textured soils due largely to impaired drainage. Where an excess of sodium carbonate or black alkali is present even though in relatively small quantities, drainage is almost completely prevented in the finer-textured soils and the mechanical condition of the soil made such that plant-growth and plant-root development are impaired.

Not all plants are equally affected by alkali. The date palm, according to Swingle[1] is the most resistant of cultural plants. Kafir corn, sorghum, sugar beets, barley, rye, mature alfalfa and asparagus are among the most resistant of ordinary crops, while wheat and oats tolerate very little alkali. Leguminous plants are as a class sensitive, although alfalfa and vetch are quite resistant. Hilgard reports that carrots, onions and potatoes produce normal yields in soils strongly alkaline, but that the quality of the crops is badly affected. Grapes, olives, almonds and figs are, in the order named, the most resistant fruit crops; while oranges, pears and apples are moderately tolerant; and, prunes, peaches, apricots, lemons and walnuts rather sensitive.

Some alkali salts are readily soluble in water and are conveyed from place to place within the soil by means of water only. It is usual to associate a toxic alkali condition of soils with an accumulation of these salts at the surface, but such may or may not be the case. Moisture is lost from the soil by direct evaporation at the surface or as vapor within the soil escaping through cracks. Moisture is also withdrawn through plant roots, and transpired by the plants. By either of the first two sources of loss the dissolved salts are left behind as the water evaporates. In the case of loss of moisture through plants, a part of the dissolved salts may be taken into the plant and a part left within the soil. Plant roots take moisture not from the soil surface nor at any one depth, but throughout a considerable area extending from near the surface to 5, 6, or even more, feet below the surface.

[1] *Bull. 53, Bureau of Plant Industry, U. S. Dept. Agr.*

The large percentage of the feeding roots of crop plants are found distributed throughout the upper 4 feet of soil. Moisture is removed from the soil to much greater depths and very much faster by plants than by direct evaporation or as vapor. It is thus frequently found that accumulations of alkali salts in toxic quantities occur within the root zone rather than at or near the immediate soil surface.

It is generally recognized that serious and extensive alkali troubles are associated only with an underground water table relatively near the surface, or as it is termed "a high water table." McLaughlin has shown that the upward movement of soil moisture by capillarity in the absence of free water extends through a few inches only in the average growing season, but may extend as far as 5 feet during a 60-day period if free water be present. Thus, if ground water is within 2 or 3 feet of the root zone of growing plants there will be a constant capillary flow of this water upward to the root zone. If the ground water contains alkali salts there will exist favorable conditions for alkali accumulations in such quantities as to prove toxic to plants. The nearer the water table is to the soil surface the more liability is there to surface accumulation of alkali. A partial temporary remedy for this accumulation has, in the past, been found in applying irrigation water in sufficiently large quantities to wash the salts down into the ground water or at least below the reach of plant roots. This treatment has, however, resulted in most cases in the raising of the ground-water level to such an extent that it augments the liability of future alkali accumulation.

In the irrigation development of the past too little attention has been paid to preventive measures of alkali accumulation. The usual practice has been, and still is, to await the development of toxic alkali concentration and then attempt its cure. Soils that are naturally alkaline or that may become so by faulty irrigation may be improved by (1) employing proper methods of irrigation; (2) cropping with resistant plants; (3) using, if possible, a chemically corrective irrigation water; (4) by surface washing; (5) chemical treatment; (6) leaching the soil by irrigation and drainage. The first three of these may be termed preventive and the last three more in the nature of curative, although the early installation of drains is also preventive. The proper

irrigation practice consists in using such quantities of water applied in such a way, consistent with good crop yields, as will result in the least loss of moisture by evaporation. One object should be to redistribute occasionally any accumulation of alkali, whether surface or subsurface, through a considerable depth of soil or to leach it far down below the root zone. This can be done to a considerable extent, except in tight soils, by applying once, twice or oftener during each season a heavy irrigation or such an amount of water as will penetrate to a depth of 6, 8, or more, feet. About one-fifth of the dry weight of Australian salt brush and Russian thistle is ash or salt compounds, hence with 5 tons of dry matter harvested, 1 ton of salt would be removed. This may, in time, give some improvement. One of the most important functions of crop-resisting plants is to provide organic matter (as roots) within the soil mass, thereby furnishing food for aerobic bacteria. Using a chemically curative irrigation water is in reality a chemical treatment but is worthy of special mention. If irrigation water containing some compound of calcium, usually as gypsum, can be applied to black alkali lands the colloids will in time be flocculated and the soil made permeable and a part of the toxic sodium carbonate converted into inert calcium carbonate.

Among the curative measures employed the most frequent is that of surface washing or washing from the surface of alkali incrustations and deposits. This gives only temporary relief, although in some cases the practice has been followed successfully for years. The chemical treatment of alkali lands should be associated with drainage. Among chemical treatments may be included the application of manure, although its beneficial effect in alkali reclamation or prevention may be mechanical as well as chemical. The manure contains organic matter upon which bacteria work and from such action generate carbon dioxide, which in turn acts upon the sodium carbonate. The usual chemical treatment for black alkali has been to apply gypsum alone, but the results obtained have not proved very satisfactory. Flour sulphur has been used and gives much promise. The best treatment consists in adding gypsum and manure followed by rather frequent and deep cultivation. In any type of irrigation farming that offers hope of permanency where alkali water in limited

quantities is applied or where the soil is naturally alkaline, there must be good drainage, either natural or artificial, and at such a depth as will hold the water table well below the root zone. In heavy soils with even small quantities of black alkali it is most difficult to keep the soil open and permeable. The black alkali disperses the colloids and wholly or partially destroys drainage. One of the serious difficulties in alkali reclamation by drainage is the resulting undesirable mechanical condition of the soil. Ultimately, however, leaching the excess salts by drainage is the only permanent method of reclamation.[1] This process was successfully tried in the vineyards of Fresno County, California, by V. M. Cone and the writer in 1907 and 1908. The upper 4 feet of soil before being treated contained on an average about two-tenths of 1 per cent. of soluble salts. After drain pipes had been laid in the vineyard, the surface formed into checks and each check flooded twice to a depth of 12 inches, the percentage of soluble salts was reduced to about four one-hundredths of 1 per cent.

40. The Use of Saline Waters in Irrigation.—The area of arable lands in the arid region is far in excess of the water available for its irrigation. It is, therefore, essential for the most complete utilization of these lands to make use of all waters that can be profitably used for this purpose, whether distinctly alkaline or relatively free from dissolved salts. Practically all waters, whether surface or subsurface, contain some dissolved mineral salts and the waters of arid regions generally contain more dissolved salts than do the waters of humid regions. The quantity of soluble salts or alkali contained in the water may be or may not be sufficient to make the water safe to use in irrigation. Our present knowledge of the toxicity of various concentrations of alkali in solution does not permit us to say definitely but only very generally just what concentration of salts is permissible.

Since the soils and soil-forming materials of arid regions contain the alkali-forming materials or the salts themselves, it is easy to understand why rain- or snow-water in flowing over or seeping through such material obtains its charge of alkali salts. Seepage water whether as return seepage from irrigation or

[1] See "Drainage of Irrigated Lands in the San Joaquin Valley," *Bull.* 217, *O. E. S., U. S. Dept. Agr.*

natural seepage is one of the most prevalent sources of alkali water. Parshall[1] states that the return seepage water into the Lower South Platte River averages in quantity 5 1/4 second-feet per mile over a distance of 143 miles. In 1896, Bear River in Northern Utah gained by return seepage 181 second-feet in a distance of about 25 miles, and 22 years later this stream over the same stretch had a seepage inflow of 325 second-feet. Almost every stream of the arid West that is used for irrigation having any considerable length has a very appreciable return seepage inflow.

That this return seepage water adds to the alkali content of the stream is definitely shown by many analyses. Greaves and Hirst[2] show that the waters of Sevier River in south central Utah in flowing a distance of 60 miles gained in salt content about 400 per cent., and in an additional 150 miles the total salt content has increased to more than 600 per cent. The Pecos River at Roswell, N. M., contained 760 parts per 1,000,000 of soluble salts while 180 miles farther down the river the salt content had risen to more than 5,000 parts. Not only do these streams show an increase in salt content but also a considerable inflow of seepage water. It is not to be inferred that all seepage or drain water is excessively alkaline for such is not the case. In fact, Greaves and Hirst found that some of the drainage water contained less dissolved mineral salts than some of the streams used for irrigation. In other cases, however, the drainage water was so salty as to be unfit for irrigation. So-called "salt" springs or creeks are frequently encountered in arid regions, the waters of which are too salty for agricultural use or even to be potable for man or beast. This salty condition is usually the result of the water having at some place come in contact with beds of salt of one kind or another. For instance, a spring in Box Elder County, Utah, flowing into Bear River contains nearly 1 per cent. salt, and this spring is not considered too salty for emergency stock water.

There is generally great variation in the salt content of water from wells even in the same locality and frequently in the same well at different depths. In many places in southern California

[1] *Bull.* 279, *Colorado Exp. Station.*

[2] *Bull.* 163, *Utah Exp. Station.*

there are several water-bearing strata at different depths and the salt content of these different strata frequently varies widely. The water from one stratum may be quite safe to use in irrigation, while the water of the strata immediately above or below, or both above and below, may be too saline for the irrigation of even the most alkali-resistant plants. In one of the artesian districts in northern Utah there are found wells flowing water that has been used for years in the irrigation of land and also wells flowing water too heavily charged with alkali to be usable for any purpose. Greaves and Hirst report one such well to contain nearly 2 1/2 per cent. soluble salts and others to contain nearly 2 per cent.

There are found in waters as well as in soils many kinds of soluble salts. The principal mineral salts and those most familiar to the general public are the chlorides, sulphates, carbonates, bicarbonates and nitrates of calcium, magnesium, sodium and potassium. These salts are seldom, if ever, found alone in solution but in various combinations. Some of the salts and combination of salts are toxic, others inert, and still others stimulating to plant growth. The chemical or alkali aspect of a water is frequently changed from toxic to non-toxic, or from non-toxic to toxic by the inflow from some other source of a water containing soluble salts of a different kind. It is common to find that the water in a stream flowing any great distance may present different alkali aspects at different points in its course. The Relito River near Tucson, Ariz., presents at one point a pronounced sulphate water and at other points the water is decidedly a carbonate. The Sevier River in southern Utah, at Clear Creek, is quite free from salts and of those in solution, 76 per cent. are non-toxic carbonates, while at Siguard the water is distinctly alkaline and contains only about one-third non-toxic carbonates, the sulphates and chlorides predominating. In the upper stretches of the Colorado River the inflowing water is generally charged with sulphates and chlorides while the Gila and other streams in the lower stretches bring in water charged frequently with black alkali. The waters of a stream may show one class of salts predominating at one time and another salt in abundance at another time, depending upon the stage of the river flow. There is also a difference in the concentration of salts at different stages of stream flow as is shown in the following table:

TABLE NO. 39.—SEASONAL VARIATION IN SALT CONTENT OF SALT RIVER, ARIZONA, EXPRESSED AS PARTS SALT PER MILLION OF WATER

Date	Total salts	Composition of the waters							
		Na	Cl	SO_4	CO_3	Ca	Mg	K	SiO_2
a. Aug. 1–Sept. 1, 1899..	724	122	279	979	...	679	174	129	206
b. Sept. 2–Sept. 9, 1899..	1,100	183	315	481	154	102	233	141	111
c. Sept. 10–Oct. 9, 1899..	1,142	274	441	727	802	724	279	109	583
d. Oct. 10–Oct. 17, 1899.	952								
e. Oct. 18–Dec. 30, 1899.	1,026	309	409	748	117	402	284	153	465
f. Feb. 17–May 30, 1900	1,069	327	437	764	115	437	292	123	529
g. June 1–Aug. 4, 1900.	1,391	407	594	919	131	651	328	112	355

a. High and low summer water. Average of four weekly composites of samples taken daily.

b. Summer flood water. One weekly composite of daily sample taken.

c. High and low summer waters. Average of four weekly composites of daily samples.

d. Winter flood water. One composite of daily samples taken.

e. Low winter water. Average of 10 weekly composites of daily samples.

f. Low winter water. Average of 12 weekly composites of daily samples.

g. Very low summer water. Average of 8 weekly composites of daily samples.

In general the greater the stream flow the less is the alkali concentration. There are many exceptions to this rule that may prevail for a limited time only. The first rains, following a long dry spell for instance, frequently wash in a large quantity of salts which gradually diminishes in concentration to a rather constant quantity with a continuance of the storm period of the winter season.

The permissible concentration of alkali salts in a water to be used for irrigation depends upon a variety of factors, the most important of which is the chemical and physical properties of the soil to be irrigated. A specific combination of alkali salts in solution may be toxic to one soil type and beneficial to another. It is known, for instance, that a water containing only small quantities of sodium carbonate will, when applied to a clay or silt soil, disperse the colloidal material of the soil and make it impenetrable to water thus preventing aeration or drainage. Black alkali may be developed in a soil under conditions which frequently exist naturally in many localities as has been shown by Breazeale.[1]

[1] *Jour. Agr. Research*, Vol. X, pp. 541–590.

Alkali is detrimental to plant growth in several ways which may be summarized as follows:

1. The flow of the soil solution into the root cells may be prevented by a too high specific gravity of the soil solution resulting from a too high alkali content, thereby starving and choking the plant.

2. Alkali tends to change the structure of the plants and may either stimulate or retard transpiration.

3. Alkali may disperse the colloidal material of the soil and thus prevent the penetration of water into the soil or the drainage of water from the soil. It also prevents aeration and the development of aerobic bacteria.

4. By directly burning the bark of the plant at the soil surface thereby preventing sap flow.

There is such a variety of conditions affecting the toxicity of any specific alkali water for irrigation that to give a list of streams used for irrigation and their chemical analysis would at the most mean but little.

Certain orchard soils, irrigated, according to Forbes, with water taken from the Salt River, Arizona, which contained soluble salts varying in amount from 520 to 1,570 with a mean of 1,070 parts per million, accumulated from 0.111 per cent. to 0.426 per cent. in a period of about 10 years.[1] Two samples of Wyoming water which contained 57.1 and 235.8 parts alkali salts per million, before irrigation, were shown by Slossen from analysis of the waste waters, to have made annual deposits in the upper 3 feet of soil which would in a period of 10 years, have amounted to 0.067 and 0.278 per cent. respectively.[2] The Bureau of Soils, U. S. Department of Agriculture, speaking of conditions in the Pecos Valley, New Mexico, said:

> Five hundred parts of soluble matter may be taken as the extreme limit of endurance for plants, while 250 to 300 mark the danger point at which the results of the use of water are very uncertain.

That this estimate is conservative, seems evident in view of the fact that for centuries past waters containing from 4,000 to 8,000 parts per million have been successfully used in crop production, according to Means, by the Arabs in the Algerian oases.

[1] *Ariz. Bull.* 44, p. 116.

[2] *Wyo., Bull.* 24, pp. 114, 117.

The remarkable success attained by the Arabs with such waters is dependent upon frequent, heavy application of water and thorough drainage by open ditches or tiles.[1] The efficiency of frequent flooding is well illustrated in the following table after Forbes showing the relative alkali content in furrows and rows subsequent to the use of saline water in furrow irrigation.

TABLE NO. 40

Depth in feet	Uncultivated tree row	Temporary ridges	Furrows flooded every 8 days
	Per cent. of alkali in soil	Per cent. of alkali in soil	Per cent. of alkali in soil
1	0.305	0.295	0.043
2	0.099	0.070	0.045
3	0.092	0.055	0.046

Note that the uncultivated row contains, in the first foot, seven times as much salt as the furrow, and in the second and third, only twice as much as the soil under the furrow. Forbes noted further that the crest of a ridge in a strawberry plat contained 0.20 per cent. in the surface foot as compared to 0.061 per cent. in the bottom of the adjacent furrow. Hilgard observed that in a period of 3 years, water containing 1,700 parts of soluble salts per million, caused complete defoliation of orange trees near Corona, Calif., and increased the per cent. of salts in the soil, originally 0.0174, four times. He says, further, that the upper limit under ordinary practice in California is 1,200 parts. Water from artesian wells containing from 1,750 to 2,000 parts mineral salts per million have been successfully used for irrigation in South Dakota.

The general statement of permissible per cents. of mineral matter in irrigation water involves a knowledge of the character and relative proportion of the alkali salts in both soil and irrigation water; the crops grown; the soil texture, depth and original alkali content; methods of irrigation; and drainage facilities. From the foregoing examples it is obvious that, although the parts of tolerable salts differ widely, under various conditions,

[1] *Bur. of Soils, Cir.* 10.

practical experience and chemical analysis agree in emphasizing liberal flooding and thorough drainage where saline waters must be used.

41. The Storage of Water on Farms.[1]—Farm reservoirs are built to store water for the irrigation of gardens, orchards and truck farms and to provide water for stock and household purposes.

The most common source of supply for such reservoirs is the well, from which water is raised to the necessary height by a windmill, internal-combustion engine, or electric motor. The reservoir is located as near as practicable to the well, and the discharge from the pump leads directly to the reservoir with a branch to the head of the supply ditch, thus permitting the well water to be stored, or used directly on the land.

The flow from springs, brooks, flowing wells and small creeks forms another source of supply. This is often too small for rapid and effective irrigation when used continuously, and storage is resorted to, in order to obtain a large head and also to collect the flow over night for use the following day, or over several days for use during a drought.

Storage may be resorted to also to collect drainage water from marshy ground when the run-off is too small for efficient irrigation. In like manner bogs and muck beds of limited areas can be converted at small cost from mosquito breeding grounds into serviceable reservoirs. Even the so-called dry creeks carry considerable water at times, part of which can be diverted, as a rule into a reservoir, and subsequently utilized for the watering of stock, the irrigation of land, or for other purposes.

Seepage Losses from Reservoirs.—Water escapes from unlined earthen reservoirs in two ways other than through the outlet or wasteway. A part of the contents is absorbed by or else percolates through the materials forming the bottom and sides, and another part is vaporized at the surface and passes off into the air. Were it not for the relatively large losses due to absorption and percolation, usually termed seepage losses, the large majority of reservoirs would be much more efficient. Since seepage losses may be regarded as one of the worst defects of the

[1] For a more complete discussion of this subject consult *Farmers' Bull.* 823, *U. S. Dept. of Agr.*, by the author.

common practice of storing water on farms, it cannot be too carefully considered beforehand, so as to avoid, if possible, the expenditure of money and labor in attempting to store water in material too porous to hold it.

An estimate of the probable losses in different materials may be formed with the aid of the following table.

TABLE NO. 41.—LOSS BY SEEPAGE IN RESERVOIRS COMPOSED OF DIFFERENT MATERIALS

Kind of material	Loss per square foot of wet surface in 24 hours, cubic feet	Loss per 100 square feet of wet surface in 24 hours, gallons	Loss per acre in 24 hours, gallons
Retentive clay	0.25 to 0.15	37 to 112	16,120 to 48,790
Clay loam	0.15 to 0.50	112 to 375	48,790 to 163,350
Sandy loam	0.50 to 1.00	375 to 748	163,350 to 325,830
Porous material	1.00 to 2.00	748 to 1,496	325,830 to 651,660

After a reservoir has been filled, the loss of water may be found readily by measuring the sinkage in a given time. To do this set a gage in the reservoir and when the weather is settled, there being neither rain nor wind, close the inlet and outlet gates so that no water will pass through either, and read the gage. Then in 24 hours, or at the end of any multiple of 24 hours, again observe the gage and note the difference in elevation, or sinkage, of the surface of the water. This difference as shown by the two readings of the gage, when expressed in inches and divided by 12 will give the loss of water in cubic feet per square foot of reservoir surface during the time of the test. Losses due to both evaporation and seepage will be included in the results found.

Whenever it is desirable to separate these two losses, it may be done by ascertaining the total loss and also the loss due to evaporation. The latter may be found by digging a hole in the top of the embankment of the reservoir, placing therein an ordinary galvanized-iron wash tub or garbage can and filling it to within a couple of inches of the top with water taken from the reservoir. The loss of water in any number of days can then be found by measuring from the lip of the tub to the surface of the water at the beginning and end of the period. About three-fourths of the

daily loss by evaporation as determined by the small can would represent the daily loss from the surface of the reservoir. Deducting this loss from the total daily loss due to both evaporation and seepage as indicated by the reservoir gage would give the loss due to seepage.

In building earthen reservoirs for farm use, more or less precautions should be taken to lessen seepage losses. The digging of a trench near the center of the ground where the embankment is to rest and filling it with puddle is a safeguard against seepage losses. Then, when the reservoir is built, if muddy water can be run into it, allowed to settle and then withdrawn to give place to another filling of turbid water, it will help tend to make it more water-tight.

A lining of concrete is the most effective, but it is likewise the most costly. Such a lining usually costs from 8 to 12 cents per square foot, or from $800 to $1,200 per acre-foot of water stored.

If clay can be found within an economical hauling distance, it may be hauled by teams. In lining with clay a reservoir intended for irrigation purposes only, a good plan to follow is to cover the bottom and porous slopes with a mixture of clay and coarse gravel to the depth of several inches and when sprinkled or otherwise moistened, use the site as a feeding ground for sheep or other farm animals. In cases where this plan is not practicable, the layer of clay should be as thoroughly pulverized as possible, the coarse gravel added and the mixture moistened and tamped by hand. The addition of coarse gravel ranging from the size of peas to that of walnuts forms a clay concrete more stable and compact than clay alone and none the less impervious.

Inlets.—As a rule, water is conveyed to farm reservoirs through pipes. Of the several kinds of pipe described in Art. 15, the following may be named as suitable for inlets: sewer pipe, concrete pipe, machine-banded wood pipe, steel-riveted pipe and lap-welded steel pipe.

Outlets and Gates.—All kinds of pipe noted under "Inlets" with the possible exception of wood pipe, may be used for outlet pipes. To these should be added cast-iron pipe, which is well adapted to this purpose. The main things to consider in building outlets are prevention of leaks and breaks, sufficient capacity, and a ready means of turning on and shutting

off the flow of stored water. The simplest kind of an outlet consists of a pipe to which is attached a valve or gate, laid with its upper end on the floor of the reservoir and extended

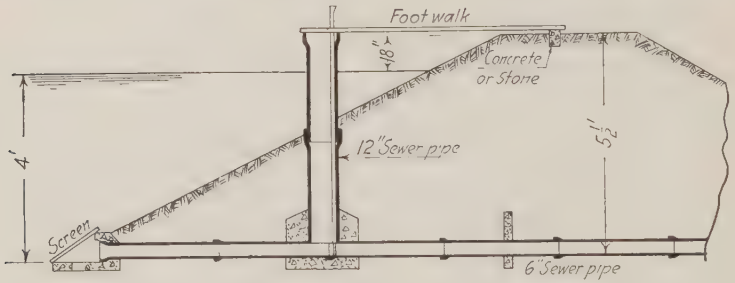


FIG. 83.—Outlet pipe and gate for a small reservoir.

under the embankment on a slight grade to a point a few feet beyond the toe of the outer slope. Usually, however, conditions call for something more. For example, trash, weeds or debris

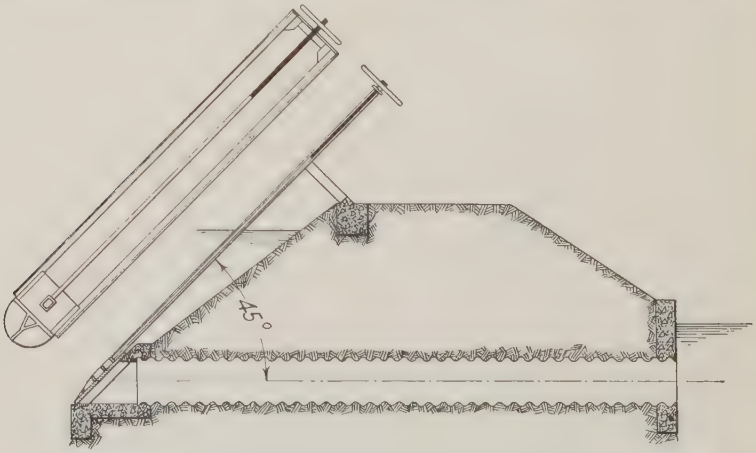


FIG. 84.—Outlet for small reservoir, with Hardesty sloping lateral gate.

may collect at the entrance to the outlet pipe and choke off or greatly reduce the discharge. To guard against this a box, preferably of concrete, is built around the entrance, having one end or the top or both open and covered with a heavy wire screen. It is likewise good practice to build a cut-off wall of

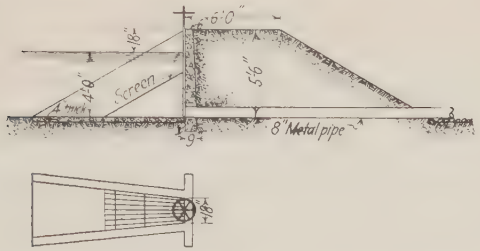


FIG. 85.—Cross section of small reservoir through gate and pipe.

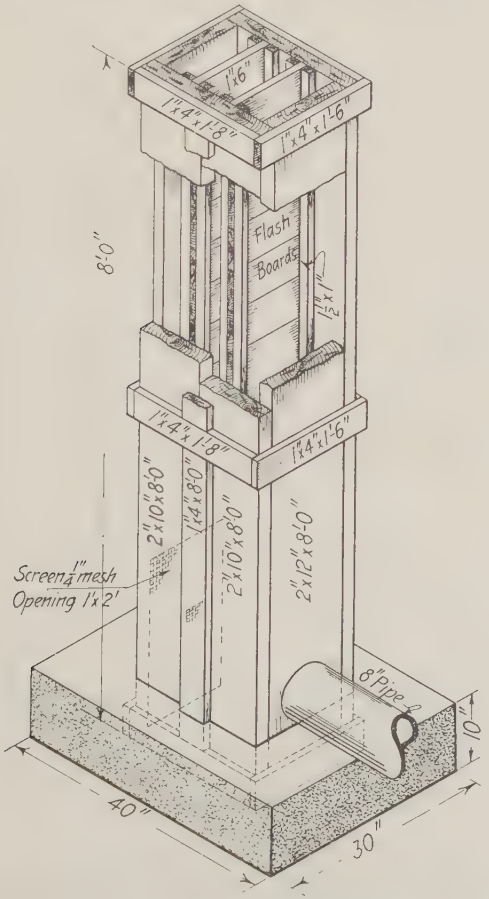


FIG. 86.—Showing the use of a double set of flash boards as an outlet for a small reservoir.

concrete or well-rammed clay around the upper part of the outlet pipe to prevent the escape of water along its smooth exterior surface. Again, some kind of a footbridge extending from the top of the embankment to the valve stem is necessary in order to operate the valve. These additional features and several types of gates and outlet pipes are shown in Figs. 83 to 85.

It is sometimes an advantage to have an outlet so adjusted that water can be withdrawn from the reservoir at any desired elevation. This can be readily effected by the use of flash boards, as shown in Fig. 86.

In estimating the quantity of water an outlet pipe of a given diameter will discharge under a known reservoir head, there should be taken into account several factors that tend to reduce the velocity or pressure and thereby lessen the flow. Of these the following may be named: (1) a retardation of the flow caused by friction in the interior of the pipe; (2) a loss of head in passing through a valve or other gate structure; (3) a loss of head at entrance; and (4) a lessening of the pressure and flow in passing through a screen. The effect of each one of the above in turn depends on a number of variable conditions which make it difficult to present any one set of figures that will apply to all. The following table, therefore, of outlet discharges through pipes 30 to 40 feet in length and provided with valves and screens should be considered as giving merely approximate volumes under such average conditions as are found in practice.

TABLE No. 42

Head over center of opening, feet	Diameter of pipe					
	4-inch		6-inch		8-inch	
	Cubic feet per second	Gallons per minute	Cubic feet per second	Gallons per minute	Cubic feet per second	Gallons per minute
1	0.35	157	0.52	233	1.3	580
2	0.46	206	1.06	476	2.0	900
3	0.58	260	1.42	637	2.5	1,120
4	0.69	310	1.69	758	3.0	1,350
5	0.79	355	1.91	857	3.5	1,570
6	0.89	399	2.09	934	4.0	1,800

Wasteways.—Ample provision should be made in all earthen reservoirs located in the beds of streams and fed direct therefrom to draw off the surplus water through a wasteway in order to prevent the water in the reservoir from rising above the high-water limit. This limit must always be placed at a safe distance below the top of the earthen dam. Many reservoirs have failed as a direct result of defective wasteways. They are either too small, not in the right place, or are poorly designed and constructed. Since it is impossible to estimate closely the flood flow of the creek or stream which feeds the reservoir, the wasteway should be built of ample capacity to secure a rather wide margin of safety. It should be located as far away from the dam as practicable. When the nature of the ground will permit, an excellent and safe wasteway is formed by excavating the material down to the flow line in a low gap of the margin of the reservoir. When this is not feasible, a shallow canal may be dug around one end of the dam and carried down stream far enough to prevent damage to any part of the structure. If the material of the wasteway is liable to scour, the channel may have to be paved or flumed. Since wasteways receive water at a state of rest or slow velocity, they should be designed with flaring inlets on steep grades as shown in Fig. 87.

Fig. 87.—Flaring inlet to wasteway of reservoir.

Reservoirs Formed in Stream Beds by Concrete Dams.—In recent years a demand has arisen for a more stable and permanent dam than that made of earth. This is due mainly to the more extended application of power to farm purposes and to the cheapness of cement concrete, both plain and reinforced.

The outline of one of these dams designed for a channel in bedrock is shown in Fig. 88. Another designed for a channel in gravel or other porous material is shown in Fig. 89.

42. Drainage of Irrigated Farm Lands.—The drainage of land in an arid region differs in many essential features from the drainage of land in a humid region. In the former the soil in its natural state, except near the surface, has been dry for ages and the artificial application of water brings about changes which are often very radical in character. The soil and numerous

carthen channels which convey the water permit a large part to percolate and otherwise pass downward. This escaping water finally reaches the natural water table or some impervious stratum along which it passes to lower levels, resulting in a rise of the water table. The intercepting of this waste or seepage water forms an important feature in the drainage of arid lands.

Another feature of even greater importance is the presence of soluble mineral salts. Where the water table approaches near

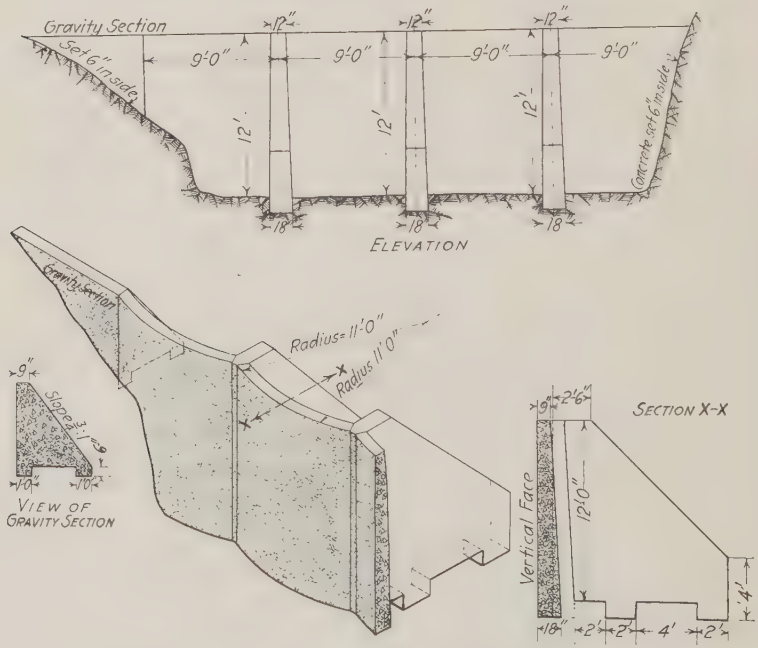


Fig. 88.—Outline for small concrete dam for rocky stream bed.

the surface of the ground these salts may become concentrated in amounts larger than ordinary crops can tolerate. The greater part of these salts, known as alkali, must be removed or their accumulation at or near the surface prevented, and drainage systems are planned with those objects in view.

Charles F. Brown divides irrigated lands needing drainage into three classes:[1] (1) those injured by excess water only;

[1] *Farmers' Bull.* 371.

(2) those affected by excess of both water and alkali; (3) those having an excess of alkali only.

The first class is the least extensive and the drainage problem is usually less difficult except where there is danger from the accumulation of alkali. Many affected areas come under the second class and the district southwest of Fresno, Calif., is a good example. Here the ground-water level has risen in

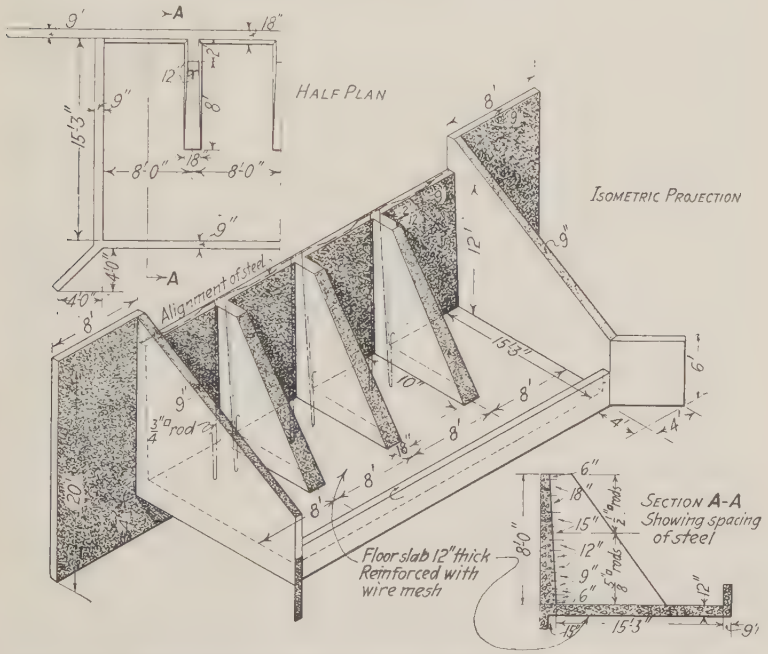


FIG. 89.—Outline showing small concrete dam for gravelly stream bed.

places over 60 feet due to losses from irrigation and leaky ditches and the resulting accumulation of mineral salts near the surface has seriously damaged much of the land.[1] Much of the low-lying land bordering Great Salt Lake is an example of the third class. Here virgin soil is so impregnated with mineral salts as to be non-productive until the greater part of such salts have been removed by copious irrigations and underground drainage.

[1] "Drainage of Irrigated Lands in the San Joaquin Valley," *O. E. S. Bull.* 217.

Need for Drainage.—Some have gone so far as to advocate that all irrigated lands be provided with drainage systems. Since only a relatively small part of most irrigated projects require drainage this is obviously an unnecessary expense. A better plan is to prevent, so far as practicable, water-logging and the rise of alkali by a skilful use of water and by keeping the natural drainage channels open. In spite of this, however, some areas are certain to become injuriously affected unless they are provided with drainage. The need for drainage should be anticipated by observing the rise of the water table by the use of small test wells and by analysis of the soil water for alkali. The early installation of a drainage system will not only afford protection from alkali and loss of crops but the cost of installation will usually be less if the water table is several feet below the surface. The depth at which the water table must be maintained to prevent injury to crops varies with the soil, crops, seasons and other conditions. The height to which water will rise by capillarity is an important factor and this is greater in clay than in sand. A depth to water of 4 feet is about the minimum for any soil, while 5 or 6 feet will be necessary for average soils and a greater depth will be required for very fine-grained soils.

In preparing the following paragraphs which aim to present an outline of the best drainage practice in the West, the writer desires to acknowledge his indebtedness to R. A. Hart, Drainage Engineer, and L. T. Jessup, Associate Drainage Engineer, Division of Agricultural Engineering, U. S. D. A.

Kind of Drains.—Covered drainage systems should be used for farm work as they are most efficient and most economical in the long run. Clay tile, cement tile or lumber-box conduits may be employed. Clay tile should be hard burned but not brittle, of good shape and condition, free from blisters and serious cracks. Cement tile should be machine made, mixed wet, of proportions of about 1:3 and well cured. Both kinds of tile should have walls as impervious as possible and be strong enough to bear the necessary weight of earth. There is some doubt with regard to the advisability of using cement tile in soil containing high percentages of the sulphates of sodium and magnesium. Lumber-box drains should be used only under the most exceptional conditions. They should be constructed with shoulders on the tops

and bottoms so that integrity of form will not depend on the nailing.

Depth of Drains.—The depth of drains must necessarily be greater than the depth to which it is desirable to maintain the water table. This difference, which is due to the slope of the water table, is less for closely spaced than for widely spaced drains; it is less for porous material than for tight subsoils. In order to increase their effectiveness, drains should cut through the more pervious formations, where such exist, at reasonable depths, and where possible the tile should be bedded on stable material. Drains in an irrigated district should not be less than 6 feet in depth, save in exceptional cases, and depts of from 7 to 8 feet are usually required for average conditions. Greater depths are much more effective, as a rule, but for farm drainage it will usually be more economical to accomplish the same results by closer spacing.

Location of Drains.—The source of the damaging water and the nature of the underground formation are factors in the location of drains. Where the affected land is located at the foot of a steeper slope, or where all of the damaging water is moving over an impervious stratum, reclamation can often be effected by placing the drain at the upper edge of the affected area. In other cases the drains are located in the lower parts or along depressions. If areas of comparatively level land having fairly uniform soil conditions are to be drained, the lines may be located with some regularity from 440 to 1,320 feet apart depending on the nature of the soil and depth of drains. If the subsoil is coarse sand or gravel, deep drains spaced a half mile or more apart may be used.

Relief Wells.—In many cases the seepage water comes from deep sources and is under pressure. Obviously, there is a limit at which drains can be laid economically, but fortunately the seepage may be intercepted by means of relief wells so located as to connect the water-bearing stratum with a drain at ordinary depth. Figure 90 shows the elevation of a drainage system so constructed as to intercept seepage from two distinct sources. The drain line cuts off the seepage from the upper stratum directly, while the relief wells convey the water under pressure from the lower stratum to the drain. These wells may be bored with a post-hole auger and usually should be cased.

Required Capacity. -It is difficult to give general rules regarding necessary capacity for drainage systems. A common rule is to determine the rate of irrigation supply for the month of maximum delivery and to provide a drainage capacity of one-third of this amount of water. This coefficient can be decreased to one-fifth for tight subsoils and usually must be increased to one-half for subsoils of coarse sand or gravel. Under ordinary conditions the drainage capacity per square mile of area contributing water to the drainage system should be about 1 1/4 second-feet for tight subsoils, about 2 second-feet for ordinary

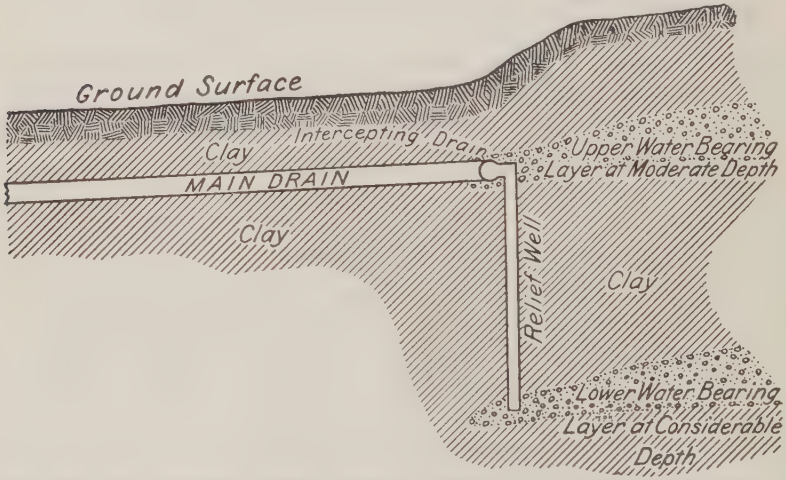


Fig. 90.—Plan and part elevation of drainage system, showing intercepting drains.

soils and from 5 to 8 second-feet for gravel. In gravel and sand the contributing area is frequently much greater than the injured area.

Grade.—The carrying capacity of a drain of given size depends mainly on the fall. The smaller the drain the more grade is required. Except for large sizes the fall should not be less than 1 foot per thousand and a fall of 2 feet per thousand or greater is much to be preferred. The tile should be laid on a uniform grade and so far as possible in straight lines (Fig. 91).

Size of Tile.—It is not economical to use tile smaller than 6 inches in diameter and the use of tile less than 4 inches in diameter is not to be considered. On the other hand it is rarely necessary

to use tile larger than 12 inches in diameter for farm drainage except in loose gravel. The number of miles of drains that a tile on a given grade will care for depends on the type of soil and the depth and spacing of drains. When laid on a grade of 2 feet per thousand a 12-inch tile will care for the discharge from a system protecting about 1 square mile with tight subsoils, about 3/4 square mile in ordinary soil and about 100 acres in loose gravel. As a general rule, it may be stated that a given size of tile up to 12 inches will carry as much water on the same grade as two lines of the next smaller size.

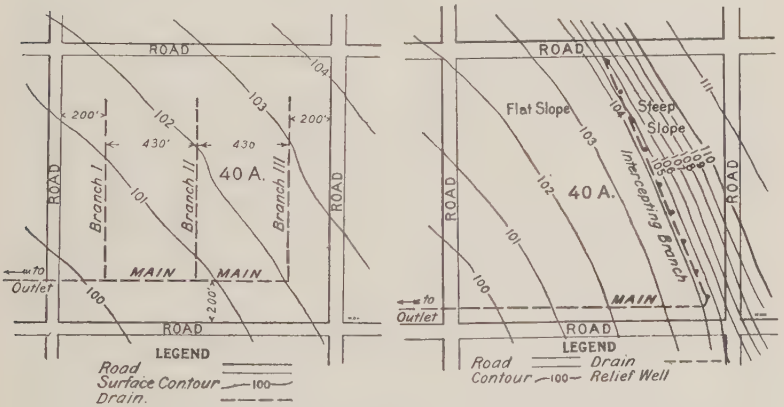


FIG. 91.—A common system of drainage applied to an irrigated farm.

METHODS OF INSTALLATION.—The use of machinery for excavation is advisable whenever possible, but often it will be found necessary to resort to hand labor. Owing to the fluxible nature of irrigated soils when wet, it is generally found expedient to employ a small gang of men on each line and to keep them working as close together as possible. Work must always commence at the outlet of each line and proceed up the slope. The trench should not be opened ahead of the work and it should be cut from surface to grade as rapidly as possible, and immediately thereafter the tile laid and blinded with several inches of earth. By systematic, rapid trenching, it is usually possible to proceed without difficulty and at a reasonable cost, but if, in spite of all precau-

tions, caving takes place, it will be necessary to brace the trench and in special cases to sheet it tightly. The best way to avoid difficulty is to choose the season of lowest ground-water table. Irrigation water should be kept off the field that is being drained and also from higher and adjacent fields if possible.

The tile should be laid carefully, in a straight line and on an even grade. The joints should be kept tight and in sandy or silty soils it may be necessary to protect the joints against the entrance of material. For this purpose burlap or heavy, tarred roofing material is used, and where gravel is available it should be placed around the joints. If the material is very soft, it may be necessary to lay boards under the tile to hold them in place or to tramp in gravel to afford a foundation. If it is impossible to keep sediment out of the line during construction, it is advisable to flush it occasionally with irrigation water. Flushing should be resorted to if sediment makes its way into the drains at later periods.

Backfilling.—Actual backfilling should be done after the tile laying is complete. Power machines are made for this work but it can be done by the use of plows and scrapers. The spoil should be ridged up over the trench to allow for subsequent settling. Irrigation should not be applied directly over the completed trenches and canals, and ditches should be carried across them in flumes.

Structures.—Manholes, which are constructed with the bottoms 18 inches or more below the tile level, are used for trapping sediment and for providing a means of access to the drain for cleaning it. They should be installed on large lines at junctions and changes in direction or slope. For observation purposes a standpipe of corrugated iron or sewer pipe can be installed at intervals. On systems that permit the entrance of surface water, inlets with catch basins to hold out the silt should be provided and inlets should be constructed at the upper end of most drains to permit flushing. Tile outlets should be protected with a concrete bulkhead or by installing at the lower end a section of corrugated iron pipe from 15 to 20 feet long.

Cost.—On account of the many varying conditions, it is impossible to estimate with accuracy the cost of drainage of a given tract without making a special study of that tract. A

summary of the experience that has been gained, however, warrants the fixing of certain limits of probable cost.

Farm drainage, when a single tract or a collection of small units are handled, and the soil is stable, varies in cost from $15 to $40 per acre. If the soil is unstable, however, or the material so hard as to require picking, the costs will run from $30 to $50 per acre, and if trenching work must be protected by sheeting, the cost is often considerably more.

In the irrigated sections the cost of clay tile per inch of inside diameter per foot of length averages from about 1 1/2 cents for the smallest up to 2 1/4 cents for the largest size ordinarily used. Trenching, laying tile and backfilling by hand in stable soil to a depth of 6 feet varies from 25 to 30 cents per foot. If the material is hard or unstable, the cost will run up to 50 cents per foot and if sheeting is required, the cost may nearly double this figure. Machine trenching, laying tile and backfilling to a depth of 6 or 7 feet in stable soil varies from 17 to 25 cents per foot.

CHAPTER VI

IRRIGATION OF STAPLE CROPS

43. Alfalfa and Other Forage Crops.—According to the census, 3,151,675 acres of alfalfa were irrigated in 1919 and the extent of land devoted to other irrigated forage crops was 2,322,039 acres. The value of the alfalfa crop for that year was $186,391,209, while that of the other forage crops was nearly $60,000,000. The value of no other irrigated crop, excepting rice, is anywhere near as high as that of alfalfa. These figures convey some idea of the importance of alfalfa and the preponderance of forage crops in western farming.

Lands Adapted to Alfalfa.[1]—The most essential conditions for the production of alfalfa are abundant sunshine, a high summer temperature, plenty of moisture and a fertile, deep, well-drained soil. All of these essentials save moisture exist naturally in the arid region of the United States and when water is applied it makes conditions ideal. Over half a century of experience has shown that alfalfa can be successfully grown under a wide variety of soils and climate; yet all western lands are not equally well adapted to its growth. For this reason those who are seeking such lands with a view to their purchase should first make a careful examination of the character and depth of soil, its behavior when irrigated, the slope and evenness of the surface, the presence of injurious salts and the facilities for drainage.

Preparatory Crops.—Experience has shown that it is difficult to secure a good stand of alfalfa on raw land that has been covered by a desert growth. This is true particularly of rough, uneven land on which crop rotation is not practised. It is likewise true of land thickly covered with brush. It has been found impracticable in most localities to secure a smooth, well-graded surface where fresh roots interfere with the proper use of all grading and leveling implements. The same is true of hog-

[1] See *Farmers' Bull.* 864 and 865, *U. S. Dept. Agr.*, by the author.

wallow land, where considerable soil has to be removed from the high places and deposited in the low places. It takes time and a second preparation of the surface before fields of this character can be put in good condition for the growth and irrigation of alfalfa. If crop rotation is to be followed, the necessity for a preparatory crop is not so urgent, since the alfalfa will soon be plowed under to give place to another crop. In northern Colorado, where alfalfa usually follows either potatoes or sugar beets, the surface is not plowed, but merely harrowed or disked in the spring just before seeding. If the surface is uneven it is smoothed and leveled by means of a float or drag before the seed is put in. In southwestern Kansas it is likewise considered best to plant alfalfa after some cultivated crop which has held the weeds in check. The land is plowed in the fall to a depth of 6 inches, double-disked in the spring after the weeds have started, and is subsequently harrowed. In the vicinity of Los Banos, Calif., new land is almost invariably sown to barley or corn for two seasons before seeding to alfalfa. In Utah, wheat or oats is preferred as a preparatory crop. The chief purpose of all such preparatory grain crops is to allow fresh roots of the original plant covering to decay, filled-in spots to settle, high places denuded of the upper layer of soil to weather, and in general to prepare a well-pulverized seed-bed in a smooth, well-graded field.

Seeding Alfalfa.—In selecting the variety of seed to plant main consideration should be given to the climate. Grimm alfalfa, so called from Wendelm Grimm who, in 1857, planted in Carver county, Minnesota, a few pounds of seed which he had brought from Germany, is now preferred for localities having cold winters. The branching roots of this variety as shown in Fig. 92 may serve to protect the plant from winter killing. Where there is little frost the Peruvian alfalfa is one of the best to use on account of its long growing season and heavy yields. For the central tier of western states the common variety of alfalfa is generally planted since the length of the growing season is longer and the yield somewhat heavier than those of the Grimm. In northern Colorado rotation of crops is practised and alfalfa seed is sown with a nurse crop, usually wheat or barley. The seed is drilled early in the spring with a common force-feed press

drill equipped with an auxiliary seed-box for alfalfa seed which is scattered broadcast between the rows and covered by the disk wheels of the press drill. From 12 to 20 pounds of alfalfa seed are sown to the acre.

In Yuma and other valleys of Arizona, October planting is preferred. Frequently in this dry climate the land is irrigated before seeding. It is then cultivated, seeded and harrowed.

In the Sacramento Valley of California, alfalfa is seeded generally in the spring from Feb. 15 to Apr. 15. In the San Joaquin Valley the time of seeding extends from March or earlier

FIG. 92.—Grimm alfalfa grown in Alberta, Canada, by Don. H. Bark who is seen in the illustration.

to April. The amount of seed used per acre in both valleys averages about 16 pounds.

The last half of August is the best time to seed alfalfa in the humid region. The soil is first plowed and heavily fertilized and early in the spring a hoed crop, preferably potatoes, is planted. When this crop is harvested and the soil again properly prepared it is in excellent condition for alfalfa seed. The long growing season of the Middle and South Atlantic states enables the plant to establish itself before the first killing frost. In seeding alfalfa in the humid region it is not safe to use less than 20 pounds to the acre.

Alfalfa as a Base of Rotation.—The benefits to be derived by rotating alfalfa with irrigated crops are now quite generally recognized and this practice is being followed by the more progressive communities of the irrigated region. Formerly when hay and grain crops comprised the bulk of western soil production, farmers were loath to plow under a good stand of alfalfa because it was their best paying crop. In later years the raising of beets, potatoes, small fruits and truck have well nigh forced growers to rotate with legumes in order to maintain the fertility and good tilth of the soil.

On account of the slow growth of alfalfa during the first 4 to 6 months after seeding and the long period required to reach full maturity, it is not adapted to short-time rotation such as is practised so successfully in the more elevated and cooler portions of the irrigated West where red clover is sown with grain in the spring and in less than 18 months is plowed under. This simple rotation of grain sown with clover one season and clover alone the next year, giving large returns of both grain and hay, could not well be followed with alfalfa for the reason named and for the additional reason that it requires at least 3 years for the roots of alfalfa to develop fully. So the most common alfalfa rotation in the West is 3 to 4 years in alfalfa, followed by root crops and a nurse crop of grain. If root crops are the most profitable, the tendency is to grow them until the yields and profits fall off, when the land is again restored by seeding to grain and alfalfa.

Influence of Irrigation in Root Development.—To develop a good tap root in the early stages of growth of alfalfa is desirable for many reasons. It enlarges the feeding ground of the plant and thus renders it more vigorous and a heavy yielder. It guards it from the bad effects of alternate dry and saturated surface soil by drawing moisture from beneath and it prolongs the life and usefulness of the plants by maintaining its most essential member in a healthy, normal condition.

To bring about deep rooting, the subsoil should be well drained. If water and worse still, water containing harmful quantities of salts, is allowed to rise into the feeding zone, it will injure and in time destroy the tap root. The presence of hardpan or any formation which hinders root penetration likewise forces shallow rooting. The remedy for this condition is deep plowing, subsoil-

ing or else dynamiting. It is also a good plan to apply water some time before seeding if the soil is too dry.

Perhaps the greatest objection to sowing alfalfa with a nurse crop arises from the injury done to the root development of the alfalfa. In such a practice the fodder crop is overlooked in an effort to produce a good cereal crop. The latter requires water early on account of its quick-maturing properties and being shallow-rooted it requires a moist surface soil. Both are likely to affect injuriously the proper development of the roots of the alfalfa.

The Irrigation of Alfalfa. *a. By Flooding.*—In the states of Colorado, Wyoming, Montana and Utah and to some extent in all western states, flooding, as it is termed, from field ditches and laterals is the most common method of irrigating hay and grain crops. As a rule a medium head of water is used. This is conducted through the supply ditch to the highest point of the field and is then divided into smaller heads and distributed among the farm ditches and laterals. From these in turn it is made to flow over the surface of the land, all excess water being collected by the lower laterals. The temporary field ditches are made to fit into the natural slope and configuration of the tract to be watered so as to conduct the water to the high places.

This method is well adapted to the varying slopes and irregular surface formation so common in the Mountain states. Fields which slope from 5 to 500 feet per mile can be successfully watered in this way. Besides the preparation of the land is easy and cheap since little change is made in the natural surface. On the other hand, the labor required to irrigate is excessive and of the most fatiguing kind.

The manner in which forage crops are irrigated by flooding can best be shown by outlining the practice in a few localities. In northern Colorado, for example, the head used varies from 2 to 4 second-feet and is divided into two or three laterals. Canvas or coarse manure dams are used to check the water in the laterals and to force it out over the banks and down the slopes of the fields. In less than 3 hours the upper foot of soil is usually thoroughly moistened. To apply one watering in this way costs from 30 to 50 cents per acre.

In Montana the field ditches are laid out across the slope on a grade of 1/2 to 3/4 inch to the rod or else down the steepest slope. In the first case the ditches are spaced 50 to 100 feet apart and water flows through openings in the bank made with the shovel and spreading out covers a wide space before reaching the next lower ditch. Each ditch carries from 40 to 80 miner's inches (1 to 2 second-feet) and one man can handle from 80 to 200 miner's inches in two or more ditches. The canvas dam is the most commonly used to check the flow in the ditch but earth and manure dams are also common. The earth is taken from the low side and when the dam is broken the hole is again partially

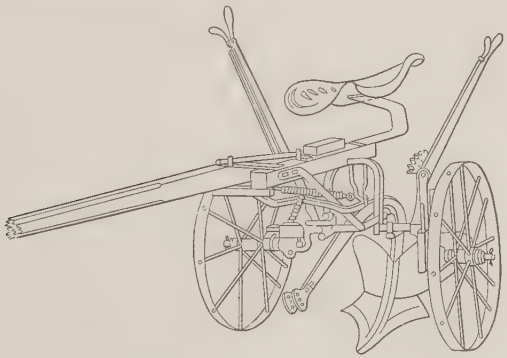


FIG. 93.—Lateral ditch plow.

filled with the same material. In making use of coarse manure for this purpose it is hauled by teams and distributed in small heaps along the ditch bank at intervals of 30 to 60 feet. Before irrigation begins it is placed in the ditch, with a thin covering of earth over its upper face. The same manure can be used for several irrigations.

In other districts of Montana the field ditches are parallel and extend down the steepest slope from the supply ditch to the catch ditch at the bottom of the field. In this practice the check dams previously described are used. The laterals are made with a lister attached to a sulky frame (Fig. 93).

In Utah the head varies from less than 1 to as high as 5 second-feet. During the spring months when the streams are running bank full, large irrigating heads are the rule, but as the stream

flow diminishes, the quantities used by the farmers likewise diminish. In this state, the farms, as well as the alfalfa fields, are smaller than those of neighboring states. One also finds more permanent ditches and turnout boxes.

b. By Borders.—The borders or lands described under Art. 21 are used extensively for the irrigation of alfalfa. When an alfalfa field is divided off into borders, it can be watered at a low cost per acre and with little labor. It is therefore a paying investment to prepare the surface for this kind of application rather than for flooding whenever conditions are suitable. It calls for a fairly smooth, uniform slope of 5 to 20 feet per mile and an available supply of water of 2 to 10 second-feet. As a rule the borders or lands are too long. One is seldom justified in exceeding 900 feet between head ditches. On more uneven slopes a much shorter run is desirable. Several second-feet are turned into each border and the number of strips which can be watered simultaneously depends on the quantity of water available in the supply ditch. Immediately after a crop has been cut and removed, a thin sheet of water will flow over the stubble and down the border in a short time without backing up. Irrigation at this stage does not, therefore, require high border levees. On the contrary, due to the obstruction to the flow of water caused by the larger growth, the time required to irrigate a fairly well-matured crop is much longer and the side levees require to be higher to prevent overtopping.

The most common size of borders in the Salt River Valley of Arizona is 66 feet wide and 1,320 feet long. A head of 300 miner's inches (7 1/2 second-feet) is turned into four borders. The time required to irrigate each set of four borders averages about 6 hours and the amount of water applied at a time varies from 2 to 4 acre-inches per acre. This water, however, is seldom evenly distributed throughout the length of the border. The soil in the upper end may be moistened to a depth of 30 inches; that of the middle to a depth of 27 inches; while that near the lower end of the border may not be moistened to a greater depth than 15 inches.

c. By Checks.—With a large volume in the feed ditch and a light sandy soil on a flat slope, alfalfa can be watered in checks at a low cost per acre for the season. In the Modesto and Tur-

lock Irrigation Districts of central California the feed ditches are designed to carry 10 to 20 second-feet. These large heads are used by the farmers in turn for short periods of time. Five second-feet flowing on a check containing 1 acre would cover it to a depth of 5 inches in 1 hour. If a head of 15 second-feet is available, three checks can be irrigated simultaneously. Irrigation begins with the higher checks and works down.

On the west side of the San Joaquin River under the Miller and Lux canal system, the check levees follow contour lines and enclose areas of 1 to 3 acres. The average head used is 8 1/2 second-feet and the time required to irrigate an acre varies from 1/2 to 1 hour and over. The checks and ditches under this system are not so well provided with boxes and gates as are those of the Modesto and Turlock districts and in consequence the cost per acre for the season is about 50 cents higher.

d. By Furrows.—Alfalfa, clover and other forage crops grown in parts of Washington and Idaho are irrigated by what is known as the corrugation method, described elsewhere, which is essentially the furrow method. The spacing of the furrows or corrugations depends on the character of the soil. In heavy, clay soils the lateral spread of water is small and the furrows are spaced about 2 feet apart, whereas in free-working, well-pulverized loam soils they are spaced about 4 feet apart.

e. By Surface Pipes.—This method is described in Art. 25.

Amount of Water Required.—Alfalfa requires more water than most crops. This is readily accounted for by the character of the plant, the rapidity with which it grows, the number of crops produced in one season and the heavy tonnage obtained.

As a result of careless practice there is a lack of uniformity in the quantity of water used, the volume applied frequently being far in excess of the needs of the crop. The majority of the records show a yearly duty of water for alfalfa ranging from 2.5 to 4.5 feet in depth over the surface, while in quite a large number of cases the volumes applied would have covered the area irrigated to depths of 6 to 15 feet.

From the large number of measurements made on the duty of water it is possible to select some that possess great value, since they indicate what can be accomplished with a given quantity of water.

During the season of 1904, careful measurements were made by C. E. Tait of the amount of water used on the alfalfa fields in the vicinity of Pomona, Calif. The rainfall at Pomona for the winter of 1903–1904 was much below the normal and amounted to about 9.1 inches. The quantity of irrigation water applied by pumping averaged 2.3 feet in depth and the yield of cured hay averaged from 1 to 1.5 tons per acre per crop, five or six crops being common. These figures are corroborated by many others collected in southern California. Perhaps in no other locality of the arid region is a greater tonnage of alfalfa obtained; yet in a climate of scanty rainfall having a long, dry, hot summer only a comparatively small amount of water is used. About a third of the 9,000 acres irrigated by the Riverside Water Company is in alfalfa and for the past 7 years the average depth applied has been 2.31 feet, while the depth of rainfall and irrigation water combined has averaged 3.18 feet.

In 1903, the writer, then Director of the Montana Experiment Station, applied different depths of water to seven plats of alfalfa with the results given in the following table. It will be seen that a high tonnage for so short a season as prevails in Montana was obtained from plat 5 with the use of 2 feet of water. By irrigating plat 6 seven times, and plat 8 eight times, it was possible to increase the yield to the amounts stated. The results of this experiment seem to confirm the best practice of southern California, which may be summed up by stating that in localities of about 12 inches of rainfall remarkably heavy yields of alfalfa

TABLE NO. 43.—QUANTITIES OF WATER APPLIED TO ALFALFA AND YIELDS SECURED, MONTANA EXPERIMENT STATION

Plat number	Depth of irrigation, feet	Depth of rainfall, feet	Total depth, feet	Yield per acre of cured alfalfa, tons
1	0.5	0.70	1.20	4.61
2	None	0.70	0.70	1.95
3	1.0	0.70	1.70	4.42
4	1.5	0.70	2.20	3.75
5	2.0	0.70	2.70	6.35
6	2.5	0.70	3.20	7.20
7	3.0	0.70	3.70	7.68

may be obtained from the use of 24 to 30 inches of irrigation water, providing it is properly applied.

Results similar to the preceding were obtained by Prof. Adams at Davis, Calif.[1] during the years 1910 to 1912 inclusive. These results are summarized in Table No. 44 and Fig. 94.

TABLE NO. 44.—SUMMARY OF RESULTS OF ALFALFA IRRIGATION INVESTIGATIONS, 1910, 1911, AND 1912

Depth of water applied, inches	Yield in tons per acre			Value of hay per acre at $7 per ton			Cost of production			Net profit per acre		
	1910	1911	1912	1910	1911	1912	1910	1911	1912	1910	1911	1912
0	3.85	6.02	6.52	$26.95	$42.14	$38.64	$ 8.65	$13.50	$12.40	$18.30	$28.64	$26.24
12	4.75	7.52	6.51	33.25	52.64	45.57	13.40	19.60	17.35	19.85	33.04	28.22
18	....	....	7.02	.....	.....	49.14	.....	.....	19.85	.....	.....	29.29
24	6.00	8.38	8.32	42.00	58.66	58.24	18.90	24.20	24.10	23.10	34.46	34.14
30	7.53	9.61	9.43	52.71	67.27	66.31	23.15	27.85	27.35	29.56	39.42	38.96
36	7.58	9.33	9.38	53.00	65.31	65.66	24.15	28.05	28.10	28.91	37.26	37.56
48	8.45	9.64	8.87	59.15	67.48	62.09	27.80	30.25	28.80	31.35	37.23	33.29
60	....	....	10.04	.....	.....	70.20	.....	.....	33.65	.....	.....	36.63

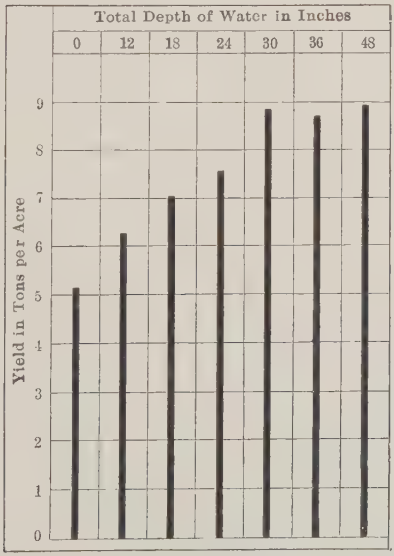


FIG. 94.—Average yield of alfalfa at Davis, Calif., from different quantities of water.

[1] *Bull.* 10, *U. S. Dept. Agr.*

Prof. Frank Adams of the University of California in cooperation with state and Federal agencies determined the quantity of water used, yields, cost of production and profits in growing alfalfa at Delhi, Calif. The results for the years 1922 and 1923 are given in the following table in the computation of which the cost of water was figured at $1.50 per acre-foot, labor of irrigating at 12 1/2 cents per hour, labor of production exclusive of irrigation at $4.00 per ton including cutting, raking, shocking, and hauling. It will be noted, however, that nothing is allowed for the use of the land, taxes, depreciation and interest on the equipment used and marketing.

TABLE NO. 45

Number of plots	Number of irrigations	Unit depth each irrigation, inches	Total seasonal application, inches	Yield tons per acre			Average value of hay per acre at $11 per ton	Average cost of production per acre	Average profit per acre
				1922	1923	Average			
5	3	4	12	7.04	4.98	6.01	$66.10	$27.05	$39.05
5	3	6	18	7.46	4.63	6.05	66.55	28.70	37.85
5	4	6	24	8.60	5.51	7.06	77.65	34.25	43.40
6	5	6	30	8.63	6.37	7.50	82.50	37.50	45.00
6	6	6	36	9.23	7.36	8.3	91.30	42.20	49.10
6	6	7	42	9.65	8.07	8.86	97.45	45.95	51.50
5	6	10	60	8.68	7.46	8.07	88.75	47.30	41.45
6	6	8	48	8.95	7.77	8.36	91.95	45.45	46.50

WINTERKILLING OF ALFALFA.—The winterkilling of alfalfa is confined chiefly to the colder and more elevated portions of the Rocky Mountain region and to the northern belt of humid states. Damage from cold is rare in Arizona, and in California it is confined to young plants. In both the Sacramento and San Joaquin valleys of the latter state the seed is frequently sown in midwinter and the slight frosts which occur occasionally in December and January in both these valleys are severe enough to kill very young plants. The belief is common that the plants are safe after they have put forth their third leaf.

In the colder portions of Montana, Wyoming, Colorado, Utah, and the Dakotas alfalfa is apparently winterkilled from a variety of causes and sometimes from a combination of causes. The

percentage of loss around Greeley, Colo., has been placed at 2 per cent. per annum. In this locality and throughout the Cache la Poudre Valley in northern Colorado most of the winter-killing is done in open, dry winters and is quite generally attributed to a scarcity of moisture in the soil. In the winter of 1907 considerable damage was done to the alfalfa fields around Loveland, Colo., on account of the long dry spell in mid-winter. The old alfalfa fields suffered most. It was the opinion of the farmers that a late fall irrigation would have prevented the loss.

Near Wheatland, Wyo., the higher portions of the fields suffer most damage in winter, and here also the cause is said to be lack of moisture in the soil, combined with the effects produced by cold and wind.

At Choteau, in northern Montana, a farmer watered, late in the fall, part of an alfalfa field which was 2 years old, and it winterkilled, while the unwatered portion escaped injury. This and other evidence along the same line which might be given go far to demonstrate that under some conditions too much moisture is as detrimental as too little.

Probably the chief cause of the winterkilling of alfalfa is alternate freezing and thawing. The damage from this cause is greatly increased when water is left standing on the surface. A blanket of snow is a protection, but when a thin sheet of ice forms over portions of a field the result is usually fatal to plants. The bad effects of alternate freezing and thawing on alfalfa may be observed at the edge of a snow bank. This crop is likewise injured by the rupture of the tap roots caused by the heaving of the soil.

During the winter of 1921–1922 a large percentage, rising as high as 30 per cent. on certain farms of the alfalfa grown in southern Alberta, Canada, was winterkilled. A commission undertook to determine the causes and remedies. Their findings may be summarized in winter protection and a hardy variety of seed. It was found that the fields which suffered most were either pastured late, or the soil was so dry as to produce little growth after the last cutting. On the other hand, little or no damage was done to fields which were protected by a growth of sufficient height. It was found that a growth of

alfalfa 6 inches high sufficed to protect Grimm alfalfa but that 12 inches was the minimum protection for the common variety.

It may be stated in conclusion that the loss to the farmer from the winterkilling of alfalfa is not as great as might appear at first. The damage is done in winter and there is ample time to plow the plants under and secure another crop, which is usually heavy, owing to the amount of fertilizers added by the roots of alfalfa. The Montana farmer who increased his average yield of oats from 50 to 103 bushels per acre by plowing under winterkilled alfalfa illustrated this point.

Cutting and Harvesting Alfalfa.—The results of experiments show that early cutting at the time the blossoms are

Fig. 95.—Alfalfa stacker built by W. L. Irvine, Pipestone, Montana.

appearing gives better yields of hay and a heavier growth for winter protection after the last cutting than later cuttings at half or full bloom. Harvesting alfalfa hay has been made less laborious by the use of the sweep rake, the hay fork and the stacker. A serviceable stacker designed and built by W. L. Irvine, of Pipestone, Mont. is shown in Fig. 95.

Cost of Growing Alfalfa.—At the present time (1925) the average cost per acre of growing alfalfa in the Rocky Mountain states on the basis of a 3-ton crop per season is approximately as given on page 273.

Interest on land valued at $150 at 7 per cent	$10.50
Taxes and interest and depreciation on equipment	4.00
Preparing land in 5-year periods	1.30
Seeding and planting in 5-year periods	0.70
Cost of irrigation water	4.00
Irrigating	2.25
Harvesting	8.35
Marketing	4.50
Total cost	$35.60

44. Irrigation of Grain.[1]—New irrigation enterprises have been settled for the most part by pioneering people who have but little capital. To settlers of this class the planting of small grain crops during the first years of their struggles with desert conditions is a necessity. Wheat and vegetables constitute the staple food supply for the poorer class, while corn, barley, oats and rye furnish food for both man and beast. Such crops, as a rule, require the smallest outley to prepare the land for irrigation, and bring the quickest returns. They do fairly well on virgin soil and by their growth fit the raw land for such crops as alfalfa and clover. They also require water at a time when snow-fed streams are high and begin to ripen before the water supply runs low. For these and other reasons which might be named, grain crops will continue to be of prime importance so long as farmers with limited means settle on the newly reclaimed lands of the West. On the other hand, the continuous cropping of grain, wheat in particular, should not be regarded as good management for the irrigated farm because of the small returns. As soon as the land is fit and the farmer is able financially to prepare the surface for more profitable crops, he should gradually convert the greater part of his grain fields into alfalfa, sugar beets, potatoes, truck and fruit.

Grain in Rotation.—The chief advantages secured by rotating grains, legumes and root crops are larger and better yields, a more uniform draft on the plant food in the soil, the privilege of growing the crop best suited to markets and greater immunity from plant diseases and crop failures. Grain used in rotation serves in many localities as a nurse crop for alfalfa and clover. In planning a rotation, however, it is obvious that the system

[1] McLaughlin, Walter W., "Irrigation of Grain," *Farmers' Bull.* 399.

adapted to one locality may not apply to another. Each system should be based on local conditions and take into consideration such factors as adaptability of soil and climate, concentrated products such as beef and cream, market conditions, size of farm, availability of labor and the like.

Preparation of the Soil.—Grain crops respond quickly at the start to a carefully prepared seed-bed. On heavy soil it is not advisable to plow very deep at first, for the deeper soil, being less exposed to the action of the elements, is not so mellow or so well aerated; but each succeeding plowing should go a little deeper until the desired depth is reached, by which time the inactive subsoil shall have become productive. In breaking up new land it is advisable to remove, if possible, all the brush and roots because when turned under they keep the soil loose and open and cause the ready loss of moisture. Brush thus covered will remain sound for a long time before decaying and will be a constant source of annoyance while it lasts.

In order that the winter moisture may be stored for spring germination, it is advisable to prepare the soil early and the ground should be plowed in the fall. Fall-plowed ground should receive a little cultivation with a spring-tooth harrow as soon as it can be worked in the spring. In the absence of a spring-tooth, the best implement is the spike-tooth harrow with teeth at an angle of 45 to 60 degrees. The disk harrow should not be used in preparing full-plowed ground for seeding except perhaps in rare cases, because it cuts too deep and the soil will dry out just as deep as it is disturbed. The object of this cultivation is three-fold; it pulverizes the surface mulch, it kills the first crop of weeds which start with the early warm days of spring and it levels the rough surface of the land, leaving it in better condition for irrigation. If this method is followed, the moisture will be held near enough the surface so that the grain may be drilled from 1 to 2 inches into the moist earth which lies beneath the dry surface mulch.

Where it is necessary to plow in the spring, care should be taken to have the ground sufficiently moist. It should not break up into dry clods or break down into a powdery ash heap. In the former case a suitable seed-bed can not be secured and in the latter the soil will puddle after being wet. When plowed it

should be dry enough to scour the plow and moist enough to turn over in a mellow state. When the soil is too dry it is better to irrigate before plowing even though plowing be delayed in consequence. The harrow should follow the plow. If a second team is not available then the land plowed in the forenoon should be harrowed before the team is unhitched at dinner time. That plowed in the afternoon should be harrowed before night. Where leveling is necessary it should be done immediately after plowing and should be followed in turn by light harrowing. This is essential in order to hold the moisture and to get the ground smoothed down to a seed-bed while it is in a moist condition.

Seed and Seeding.—The time of seeding varies with the locality and variety of grain. Wheat may be sowed on unfrozen ground at any time from late August until well along in the spring months. Spring wheat should be planted early. It is generally conceded that the growing of fall or winter wheat is preferable to the growing of spring wheat except in sections where the former will winterkill. In growing winter wheat farm labor is more evenly distributed, less water and labor are required in irrigation and the crop matures earlier. These advantages also apply to the grains which can be grown in the fall.

In the case of spring barley and oats, early planting is not desirable. When sown too early these seeds sometimes rot before germinating and a good stand is not secured. The better plan is to have the ground well prepared with plenty of moisture under a thin, fine mulch, then wait for warm spring weather and plant at a time when quick germination can be secured.

The depth of planting will depend somewhat on the condition of the soil. One of the advantages in using a drill in seeding is to secure a uniform germination which in turn insures a uniform ripening of the crop. When a drill is used in seeding, the grain should be placed 1/2 to 2 inches in the moist earth which with a 2- to 1 1/2-inch mulch makes a total depth of planting of from 2 1/2 to 3 1/2 inches.

The variety of seed to use should be determined by local conditions, time of planting, market demands and various other factors. A safe rule to follow is to choose the variety which has been adopted by the majority in a community and found to give the best results. If any entire community is growing the same

variety there will be little difficulty experienced in obtaining seed pure, which is one of the most important considerations in successful grain culture. Care should also be taken to secure grain seed which is true to type, heavy and free from weed seed. This done, the next step is the proper treatment of the seed to prevent various diseases, principal among which is smut.

The formalin treatment consists of 1 pound of formalin of guaranteed strength and purity to 50 gallons of water.

Irrigation before Seeding.—In many parts of the arid West the winter precipitation is so light that moisture sufficient for spring germination is not stored in the soil and it is necessary to irrigate to supply the deficiency. This may be done either before or after seeding. Although the latter practice is the more common, observations and the results of demonstrations in many western states point conclusively to the fact that irrigation before seeding rather than immediately afterward is generally the better practice. In the more retentive soils of the warmer states, water may be applied during the late fall or winter months so as to store enough moisture in the soil to supply the needs of the plant until seeding time. In other localities the effect of fall plowing followed by soil moisture conservation may provide sufficient moisture without any artificial watering.

It is the land which is plowed in the spring that gives the most trouble. If it is too dry it should be first plowed and leveled, and then irrigated and harrowed when dry enough. The harrowing should be done with a spring-tooth or spike-tooth harrow. This treatment not only provides ample moisture near the surface but leaves the soil mellow and in good condition to insure an even and rapid growth of grain. It is only on the more retentive soils that this practice is likely to prove injurious in seeding.

Farmers who plow in the spring, put in the seed and take chances of the small amount of moisture in the soil being sufficient for germination usually fail to harvest a full crop. The stirring of the soil causes a loss of moisture by evaporation in the top layer where the seed is placed, and as a result germination is incomplete and an immediate irrigation is necessary to obtain a stand. The application of water at this time is liable to form a crust through which the young plants cannot force their way.

This crust also tends to rob the soil of its moisture by producing a heavy evaporation and it is not long until a second or even a third watering is required. These frequent irrigations at the start produce shallow-rooted plants which are injuriously affected by the subsequent drying out of the top soil. The bad effects of "irrigating up" a crop, as it is called, may be partially remedied by harrowing the ground in the direction of the furrows when the plants are in the third or fourth leaf.

When to Irrigate.—There are two critical periods in the development of grain crops. The first extends from germination until the plants shade the ground, the second is at the flowering or fruiting stage. The plant must get a good start. Sufficient food is present in the parent kernel to start the root growth and to force the first leaf into view, after which it must shift for itself. If moisture is scarce at this stage the necessary food cannot be obtained and a stunted growth results which can never be entirely overcome. Because of the necessity of giving the tender plant a good start it is important that the moisture should be supplied beforehand so as to make it unnecessary to apply cold water, which always checks development at this stage of growth.

The second critical period and the one which is the most vital because of the sensitive condition of the plant comes at the flowering or fruiting stage. More moisture is required at this time and immediately following than at any other stage of growth. To avoid a second shock care should be taken to supply plenty of moisture about booting time before the heads appear. This irrigation may suffice to bring the crop to maturity. However, if a shallow-rooted system has been developed by frequent previous irrigations or if even with a deep-rooted system there seems to be a scant supply of moisture, then it is advisable to give another light irrigation when the grain is in the dough. Otherwise it will not fill and will shrink in weight after harvest.

Quantity of Water to Apply.—The quantity of water to be applied at each irrigation depends upon the number of irrigations, depth of soil, nature of subsoil, the purpose for which the grain is grown, the condition of the crop, climatic conditions, and from a practical standpoint, the length of time between water turns, the available supply, method of application, the requirements of other crops, the expertness of the irrigator

and the length of time the field has been under irrigation and cultivation.

As a general rule, the soil is driest at the time of the first irrigation and more water will be required to irrigate properly at this time than subsequently. It is always safe to assume that the larger the growth of the straw the greater will be the quantity of water required at the time the head is making. Water for irrigation is generally plentiful during the early spring, but at the time the grain is filling the supply usually begins to fail. The usual practice of the farmers in the Mountain states is to irrigate heavily in the spring and use less water as the season advances.

The amount of water required by new land is usually more than that required by older land. The experience of the Bear Valley Canal Company in Utah affords an excellent illustration of the relative requirements in this regard. During the first years of irrigation in this valley a second-foot of water was used upon 60 to 80 acres and apparently the land required that amount. In recent years the amount of land actually served by a second-foot of water is much more. This decrease in the use of water is due in the first place to a rise of the ground-water level and in the second to a better understanding of the water requirements of crops and improved methods of culture.

With reference to the water requirement of cereals at different stages of growth, a relatively small amount of water is used from the time of germination until the plants cover the ground. Then there is a gradual increase in water transpired until the heading-out stage, followed by a more rapid increase until the milk stage of the grain is reached. Beyond the hard dough stage there is a sudden decrease in the amount of soil moisture needed and this lessening requirement for moisture continues until the grain is ripe. Water applied after the dough stage is reached decreases the yield and tends to lodge the grain. The largest yields are obtained by maintaining an adequate moisture supply in the soil by the necessary number of waterings until the dough stage is reached.

The results of investigations made by Don H. Bark on the medium clay and sandy loam soils in southern Idaho in the years 1910, 1911 and 1912 show that the average amount of

water used on 122 fields of grain was 1.45 acre-feet per acre. The rainfall during the three seasons of growth varied from 2 to 6 inches.

In the years 1899 and 1902, inclusive, the writer determined the amount of water used on 25 grain fields in 3 widely separated valleys of Montana and the average was found to be 1.31 acre-feet per acre. To this amount should be added the rainfall which averaged 0.42 acre-foot per season.

Methods of Applying Water.—The experience of the Greeley colonists in Colorado and of others throughout the West goes far in demonstrating that grain growing year after year on irrigated land is not a profitable business. In order to yield fairly remunerative returns it must be rotated with other crops. Accordingly the preparation of land and the manner of applying water must also be adapted, not only to grain but to other crops in the rotation. At least three of the various methods previously described are suited to a combination of this kind. These methods are flooding, small furrows and borders.

Irrigating grain by flooding is the usual practice in Montana. There the field ditches, spaced from 60 to 90 feet apart, are made with a 14- or 16-inch double mouldboard plow attached to a sulky frame and drawn by three horses. The ditches are cleaned out with a steel or wooden shovel of the same width, drawn by one horse. This implement also forms the earth dams in the ditches and is locally styled a dammer. The horse walks in the furrow made by the ditch plow, and the loose earth in the bottom and sides is carried by the steel shovel and dumped in heaps about 60 feet apart. A stream of 100 miner's inches or thereabouts is turned into the supply ditch and divided between two adjacent field ditches. When one piece of ground is thoroughly soaked to a depth of 12 inches the dam is opened and the water rushes through until it is checked by the next earth dam. By this method and with a good head of water one man can irrigate on an average 5 acres per day. If the flow of water is small and intermittent, the average may be cut down to 2 acres. The second irrigation is applied in the same way but the amount of water used is considerably less.

In some sections of the West the field ditches, instead of being located on the grade lines extend down the steepest slope. Each

irrigator is given about 125 miner's inches of water which is divided between two laterals. Instead of earth, half-rotted straw or stable manure is often used to form the checks, which are spaced about 65 feet apart. As soon as the first irrigation is completed the dams are reset for the second irrigation. In resetting the dams the manure or straw is mixed with the earth while both are kept damp thus forming a stronger and more impervious dam.

In irrigating grains by small furrows spaced 2 1/2 to 3 feet apart, commonly called corrugations, from 1 to 2 second-feet are turned into the head ditches and distributed among the furrows. One second-foot may well be divided among 50 to 150 furrows depending on the character of the soil and the slope of the field. The length of the furrows should not exceed that of a square 10-acre tract (660 feet) and when a 40-acre field is irrigated it should be divided into three equal parts by head ditches, thus making the length of furrow in each part 440 feet. The water should be run long enough in the furrows to moisten the soil between them.

The irrigation of grain by the border method (Art. 21) does not differ in any essential from the description given elsewhere for the irrigation of alfalfa and other crops by this method.

Harvesting, Marketing and Profits.—Irrigated grain is confined to relatively small areas and has a long and heavy straw. Both of these conditions are unsuited to the combined harvester so commonly used on the dry farms and in the Mississippi valley. The sheaf binder is used almost universally in harvesting irrigated grain. This implement drops the grain bound in bundles either scattered or in piles. These are immediately placed in shocks by hand. Occasionally the bundles are hauled from the shocks to the farm stack yard to cure but more often they are hauled from the shocks directly to the thresher.

The well-managed irrigated farm has very little grain to market. But little wheat is grown and the oats, barley and corn or other grains are fed to stock of various kinds, thus insuring a much higher return than can be realized from the direct sale of the grain.

Cost of Growing Wheat.—The cost, in 1923, of growing wheat in the Rocky Mountain states on the basis of a yield of 25

bushels per acre and exclusive of the use of the land, taxes, and interest and depreciation on equipment is about as follows:

Preparation of land including plowing, harrowing and levelling	$5.30
Seeding and planting	2.10
Irrigating	2.20
Harvesting	6.90
Hauling of elevator	1.75
Total cost per acre	$18.25

45. Irrigation of Potatoes.—Peru is the birthplace of the Irish potato and native plants are found in localities having a mean annual temperature of about 52°F. being about 48° in July and 54° in November. In this country potato production is most successful where the range of mean temperature is 45° at the time of germination and less than 70° during the growth period. Potatoes are grown successfully in Wyoming at an elevation of 8,000 feet and also at the lower elevation in the states along the Pacific coast and are found from Montana on the north to New Mexico and Arizona on the south. Intense heat is detrimental to the potato. In general it may be said that for the best yield the mean temperature of the air should not rise above 70 to 75°F. for any considerable time while the tubers are growing.

Soil.—Potatoes under irrigation require a loose, friable soil with good underdrainage, an ideal soil being a sandy loam with gravelly subsoil. A heavy clay or adobe soil is not well adapted to this crop.

Rotation.—Some system of rotation is very essential for the best results in the growing of potatoes, for continuous cropping will exhaust the soil in a short time and the yields will decline unless fertilizers are applied. Even though manure or artificial fertilizer is applied, fungus diseases, such as scab, will attack the tubers if they are grown on the same ground year after year. In the West, alfalfa or clover should be included in any rotation with potatoes in order to restore the nitrogen taken from the soil by the potatoes. Small grain and sugar beets can also be grown to advantage in such a rotation though many farmers simply grow alfalfa and potatoes alternately, letting the alfalfa remain 3 to 5 years or longer and following with potatoes for 1

or 2 years, never more than two. If grain is grown, the order should be alfalfa, potatoes, grain; or alfalfa, grain, potatoes, grain. The advantage of the last named rotation is that the alfalfa is sometimes hard to kill out and if a crop of grain is grown preceding the potato crop the alfalfa will be effectually eliminated.

Preparation of Soil.—The ground should be carefully leveled to a uniform slope so that the irrigation water can be easily confined to the furrows. The importance of deep plowing, followed by a thorough harrowing in order to put the soil in good shape to receive the seed cannot be too strongly recommended. If the season has been unusually dry it is sometimes advisable to irrigate before plowing in order to insure a liberal supply of moisture at the time of planting.

Seed and Planting.—Medium-sized potatoes, with clear, healthy skins and shallow eyes should be selected for planting. The grower will find it of advantage to select his seed potatoes in the field, choosing seed from the large hills. Ground which has grown scabby potatoes the previous year should not again be planted to potatoes no matter how thoroughly the seed may be treated to prevent this disease. If there is danger of scab, ground should be selected where alfalfa or grain has been grown for a number of years. As an extra precaution it is well to treat the seed before cutting with a solution of corrosive sublimate or formalin or with gas. *Farmers' Bull.* 407 of the Department of Agriculture describes the preparation and use of these solutions. The pieces should not be cut too small, quarters or halves usually being recommended by the best growers. Many good authorities are now recommending the planting of whole potatoes of medium size.

The tubers should be planted 3 to 6 inches deep and 12 to 18 inches apart in rows 2 1/2 to 3 1/2 feet apart, depending on local conditions. Shallow planting is best on heavy soils, while on light sandy soils 6 inches or even more is not considered too deep. The amount of seed per acre depends, of course, on the distance between hills and the size of the seed pieces, but 700 pounds may be considered a fair average. Where this crop is grown on a commercial scale a planter should be used but great care should be exercised to get a uniform stand. Planting pota-

toes in plow furrows should never be practised as the seed should be entirely surrounded with soft earth to permit of the proper development of the roots and tubers.

Cultivation.—In arid regions frequent cultivation will aid greatly in conserving the soil moisture and may take the place of one or more irrigations. While the plants are quite small the field can be harrowed without injury and this kills the small weeds and serves as a cultivation. Other cultivations between the rows with an ordinary cultivator should follow rapidly until the vines are large enough to shade the ground when it is usually considered that no further cultivation is necessary although some irrigators prefer to cultivate after every irrigation so long as it can be done without injury to the vines. These later cultivations should be very shallow, however, in order not to injure the tubers.

Spraying.—It is sometimes necessary to spray potato vines to protect them against the ravages of the potato beetle. There are machines on the market which enable the grower to get over his fields very rapidly and a thorough spraying at the right time greatly reduces the injury by the beetles.

Irrigation.—Potatoes should never be "irrigated up," that is, it should never be necessary to irrigate the field to sprout the seed, as it is impossible to get a uniform stand in that way. Care should be taken that sufficient moisture is in the ground at the time of planting to supply the needs of the plant for the first 20 days. Irrigation should be delayed as long as possible without checking the healthy, vigorous growth of the vines. Under ordinary circumstances the first irrigation is applied about the time the vines begin to bloom and from this time on until maturity the soil should be kept well supplied with moisture so as not to check the growth. Allowing the soil to dry out and then applying a copious irrigation is apt to produce knotty tubers and otherwise injure their quality.

Furrow irrigation is the only practical method for potatoes. The common practice in irrigating potatoes is to make an opening in the ditch bank with the shovel at intervals, one opening supplying water to several furrows. This method can be improved on by inserting wooden or metal spouts in the ditch bank for every other row and raising the water in the ditch by

means of a check box or canvas dam until it flows through these openings. This enables the irrigator to control the flow of water in each furrow much better than by the first-mentioned plan.

Furrows should be made deep so as to allow the water to be drawn up to the vines by capillarity. This lessens the danger of saturating the soil and causing it to bake, a condition which should always be avoided if possible. At the last cultivation before the first irrigation the fenders should be taken off the cultivator and the shovels turned so as to crowd the earth toward the vines. The furrow thus made should be deepened by going over the field again, using double-winged shovels on the cultivator or a double mouldboard plow. This makes a furrow about 12 inches deep measured from the crown of the plants and 12 to 16 inches wide across the top. The chief advantages of deep furrows are: They provide an abundance of loose earth to place around the tubers; they lessen the risk of the water coming in contact with the vines; they prevent an excess of water around the tubers and they allow the moisture to be drawn up from below, thus supplying a constant and uniform quantity to the roots.

Where it is possible to get a large head of water, one irrigator can handle 2 second-feet without waste. With such a stream he can keep water running in 40 to 50 rows at a time and under typical conditions, that is, with a slope of 25 feet per mile and rows 1,000 to 1,200 feet long, the water should reach the end of the rows in 3 or 4 hours. Where smaller heads must be used it is sometimes necessary to run water in the rows from 24 to 48 hours in order thoroughly to irrigate the crop. Two or three irrigations usually suffice to bring the crop to maturity. A well-known method of determining when the crop is in need of moisture is to dig into the earth near the tubers and press a handful together; if it crumbles apart when released the crop should be irrigated. When the vines have a dark-green color it is also an indication that they need water.

Experiments conducted at the Experiment Stations of Idaho, Montana and Utah indicate that better quality and as good yields of potatoes can be secured by the use of a moderate amount of water. The amount required varies with the soil and the season, but generally speaking the total amount applied

during a season should not exceed 2 feet in depth over the field. With frequent cultivations and care in the distribution of the water a much smaller amount will be ample.

Opinions differ regarding the respective merits of applying water in every row or every alternate row. The majority of potato growers irrigate in every row but many employ the alternate method successfully. With a loose, friable, sandy loam which allows moisture to spread rapidly laterally water applied to every other furrow will moisten the intervening space sufficiently to maintain the proper condition of soil moisture. At the second irrigation the rows not watered the first time should be irrigated. Where only a small irrigation head is obtainable, and with a soil as described above, this method undoubtedly possesses merit.

As regards the time of irrigation, if the soil is moist at the time of planting, the first of these may be applied when the vines are 4 to 6 inches high, the second when the tubers begin to form, the third when the vines are in bloom and later a fourth if needed. If only one irrigation can be applied it should be at the time of full bloom providing there was an ample moisture content in the soil at germination.

Good practice in the growing of this crop may be summed up thus:

1. See that there is plenty of moisture in the soil at the time of planting. Irrigate before planting if necessary but never irrigate to sprout the seed after planting.
2. Run a small stream of water in a deep furrow so that moisture will be drawn up to the tubers instead of soaking down to them.
3. Do not irrigate too soon. Wait until the crop is plainly in need of water and then keep the ground well supplied with moisture until the potatoes have matured.
4. Conserve the moisture and aerate the soil by frequent light cultivations. If this is done two or three irrigations will usually suffice.

Harvesting and Sorting.—When the skin of the potato is firm and cannot be rubbed off and the vines are dead, the crop is ready to harvest. The work of digging, sorting and marketing or storing should then be rushed through in order to avoid danger of loss from freezing.

Where potatoes are grown on a commercial scale it is best to have a potato digger. Sometimes a number of farmers can combine and purchase a digger to advantage. There are a number of different makes on the market at varying prices. The machine should be kept some distance ahead of the pickers in order that the potatoes may have time to dry out before they are sacked.

The sorting can be done either in the field at the time of harvest or later when they are to be marketed but the former method is the better. There are also machines which sort the potatoes. These consist simply of a set of screens of different-sized meshes which separate the small potatoes from those of marketable size.

STORING.—It is not always convenient or advisable to haul the potatoes directly to market from the field and it is, therefore,

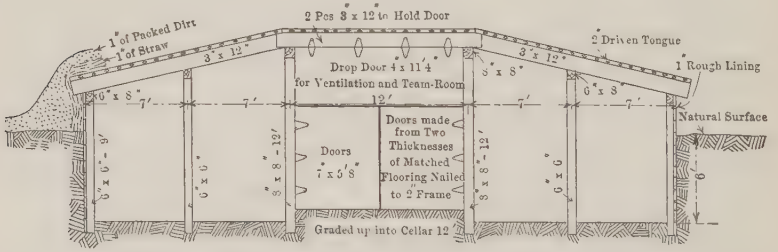

1" of Packed Dirt
1' of Straw
2 Pcs 3" x 12" to Hold Door
2" Driven Tongue
1" Rough Lining
Drop Door 4 x 11 4
for Ventilation and Team-Room
Doors made from Two Thicknesses of Matched Flooring Nailed to 2 Frame
Doors
Natural Surface
Graded up into Cellar 12'

FIG. 96.—End elevation of a potato cellar.

often necessary to provide storage for part of the crop at least. In building a storage house for potatoes it should be constructed so as to provide an even temperature just a little above freezing, a good circulation of dry air and convenient arrangements for putting in and taking out potatoes.

Figure 96 shows an end elevation of a potato cellar near Idaho Falls, Idaho. The cellar is 98 feet long and 40 feet wide. The dimensions of the frame are as shown in the sketch. The sides and ends are boarded up with 1-inch rough lumber and the portions above the natural surface of the ground are banked with earth and straw. The roof consists of 2-inch rough planking covered with a foot each of straw and packed earth. The main entrance is protected by a covered driveway 28 feet long, 11 feet wide and 9 feet high built of rough 1-inch lumber. There are six 1-foot square chutes in the roof on each side for use in filling

the top part of the cellar and four 2- by 3-foot traps in center of roof to admit light and air. In cold weather the traps are covered with sacks and in very severe weather a covering of fresh barnyard manure is added.

MARKETING.—The man who grows potatoes commercially should keep in close touch not only with his local market but also with the large markets of the country. He should endeavor to ascertain just what characteristics a potato should possess to be a good seller and should strive to produce that kind of potato. Very large or very small potatoes are not in demand. A medium-sized potato, with shallow eyes and smooth, healthy skin will always command the highest price. If the grower contemplates holding his crop in storage for better prices he should take into account the extra labor involved, the loss from shrinkage of the stored crop and the danger of loss from freezing in very cold weather or from other causes. Cooperation among growers in raising uniform varieties and in marketing their crops is of great value in sections which are distant from large markets.

COST OF GROWING.—The cost of growing potatoes under irrigation varies somewhat due to the difference in the amount of seed planted, the price of the irrigation water, the yield, etc. However, it is believed the following tabulation represents the average cost of the various items. This does not include the cost of fertilizer which if used would add $3 or $4, or taxes and interest on the value of the land.

Preparing ground	$3.00
Cutting seed and planting	2.50
Cost of seed	8.00
Cultivating and hoeing	4.50
Irrigating	4.50
Harvesting	9.00
Sorting	2.00
Sacks	5.00
Marketing	6.00
Spraying	2.00
Total	$46.50

The cost of the seed is the item subject to the greatest variation. This is readily understood when it is remembered that the amount

of seed planted may vary all the way from 600 to 3,000 pounds per acre.

Yields and Profits. According to the census the average yield of potatoes in the United States in 1919 was less than 90 bushels per acre. In the same year the average yield in Idaho under irrigation was over 169 bushels per acre.

46. Irrigation of Sugar Beets. Sugar beets in common with many other crops cannot be shipped profitably a long distance and it is therefore necessary that the greater part be grown near a sugar factory. Sugar companies operating in Colorado ship part of their supplies by rail over distances of 75 to 200 miles but the bringing in of these outside products is merely to supplement what is home grown. In general the management of a factory must be assured that a large enough acreage is planted to sugar beets each year to keep the plant running sufficiently long to make the enterprise profitable. The grower and the sugar company are therefore interdependent.

Sugar-beet factories have capacities ranging from 400 to 3,000 tons of beets daily and the "campaign" or time the factory runs is from 80 to 120 days, varying with the locality and the season.

Each sugar-beet grower is required to enter into a contract with the factory before the beginning of the crop-growing season. These contracts provide that the grower shall prepare the area which is to be devoted to beets in a thorough manner and that the seed will be planted and the beets grown, blocked, thinned, harvested and delivered in accordance with instructions and under the supervision of duly authorized agents or field superintendents of the company. The company agrees to commence receiving beets as soon as they are matured. Instructions are given in the contracts regarding the harvesting, marketing and siloing of the crop. The growers are privileged to employ a man at their own expense satisfactory to the company, to check the tare and weight of the beets or the beet polarization of the laboratory. Settlement is made on or about the tenth of each month for all beets received during the first half of the preceding month and on the twentieth for the last half of the preceding month.

The American Beet Sugar Company, in its contract for 1925, agrees to furnish seed at 15 cents per pound which must be planted on the acreage listed before May 20 (Arkansas Valley, Colorado)

unless the company gives written consent to plant after that date. Growers receive 85 cents per ton for siloed beets delivered. The price per net ton of beets is based on the average sugar content and also on the average net return f.o.b. factory received for sugar manufactured and sold by the factories located in the Arkansas Valley in Colorado. Thus when sugar is selling for 8 cents per pound the grower receives $8.20 per ton of beets having 14 per cent. purity and $10.96 per ton when the purity is 18 per cent.

Sugar beets are grown successfully on almost all classes of soil from heavy black adobe to sandy and silt loams. The heavy soils are of course harder to cultivate but if properly handled such soils will produce a large tonnage of beets high in sugar content.

Rotation of crops is just as essential in the growing of sugar beets as with other crops. One instance is recorded where a field was cropped to sugar beets for 7 successive years with the result that the tonnage was reduced from 33 to 14 tons per acre. The most common rotation is to follow beets with grain, then alfalfa, then potatoes or other cultivated crop and back to beets again. Beets should not be grown more than 3 years in succession and 2 years is preferable.

Preparation of Soil and Seeding. In preparing a field for seeding, deep fall plowing (10 to 12 inches) is generally considered very essential. Except in California, it is thought best to allow the field to remain in its rough condition so as to catch the snow and to allow the soil to be thoroughly aerated. In early spring it is double-disked, irrigated if necessary and replowed to a depth of 3 or 4 inches. After this second plowing the ground should be harrowed down to fine seed-bed. This last is very important since the beet is a tender plant at first and needs every possible encouragement to develop its root system.

The seeding is usually done by the sugar company, the company furnishing the seed and doing the seeding at prices stated in the contract. An ordinary four-row force-feed beet drill is used, 15 to 25 pounds of seed being sown per acre. The seed is planted 1 to 2 inches deep, and the rows are spaced 16 to 20 inches apart or they may be alternately 16 and 24 inches apart. The common practice in Colorado is to space the rows 20 inches apart. The

time of seeding in California extends from the end of October to May. In most other sections of the West the time is from April 10 to May 20. Sometimes rain falls before the beets have sprouted and a crust forms. This crust must be broken and the usual methods are to harrow the ground with the teeth of the harrow slanting back or to use a corrugated roller. *Farmers' Bull.* 392 states: "Seemingly the best way is to use 'spiders' on a beet cultivator . . . The sharp points of the implement prick into and break up the crust without otherwise disturbing the top soil."

Care of the Young Plants.—In caring for the young plants there are a number of operations necessary in addition to frequent cultivations with horse cultivators. The first of these is called blocking and thinning. The blocking is done with a hoe by cutting out part of the young plants, leaving the remainder in bunches 8 inches to 1 foot apart from center to center. All but one plant in each bunch are then removed by hand. This gives the beet sufficient room to grow to a desirable size. Beets weighing 1 to 3 pounds are preferable. This work is usually done by contract and often small plants which should have been pulled are overlooked and these are removed at the second hoeing which follows in about 10 days. A third hoeing is usually necessary, following the first irrigation, which consists chiefly of cutting out or pulling the large weeds which are missed by the cultivator. A cultivation should follow each hoeing and each irrigation but this is not done in some localities. In Colorado very few growers cultivate after irrigation begins.

Irrigation.—As with other row crops, it is very important that a field intended for beets be carefully leveled to a uniform slope before the crop is planted. The benefits from such a course will be felt as long as the land is farmed. If there are irregularities in the field, part of the crop will suffer from lack of water and other parts will get too much and it will be impossible to confine the water to the furrows.

The furrow method is used almost exclusively in all western states except California and Kansas. In these latter states flooding in checks or borders is practised. This is due to the fact that winter irrigation is practised to a great extent, most of the water being applied before the crop is planted. Slip-joint pipe

is also used in parts of southern California, and in the neighborhood of Lewiston, Utah, and southern Idaho a method of subirrigation is practised. These methods are the same for sugar beets as for other crops and have been described elsewhere in this volume.

Where furrow irrigation is employed the furrows are made with a furrowing sled or with a cultivator, using the furrowing shovels and fenders. The furrows receiving water from one supply ditch should not exceed 500 feet in length and 300 feet would be better in most cases. Cross-ditches should therefore be constructed at intervals of 300 to 500 feet at right angles with the beet rows for all ordinary slopes. These consist simply of furrows made with a single or double mouldboard plow. Water is supplied to the furrows in much the same way as described for the irrigation of potatoes.

Water should be supplied only as needed throughout the growing season. From 2 to 4 applications are usually sufficient. Beet tops may wilt during hot days even when the ground is abundantly supplied with moisture but if they still appear wilted in the early morning it is a sign that they are in need of water. The ground should never be allowed to become dry enough to check the vigorous growth of the beets. Irrigation should be discontinued long enough before harvest to allow beets to mature. This is usually 4 to 6 weeks but the grower must use his best judgment in this matter combined with an observance of the practice of the most successful growers in the community.

Some difference of opinion exists as to the relative merits of night and day irrigation. Those who advocate day irrigation claim that they can control the water better in the daytime and thus insure a more even distribution and less waste. The advantages of night irrigation are that water will go farther at night due to less evaporation, that the temperature of the water is higher and that there is less danger from scalding. In any sections where a system of rotation is practised irrigators are compelled to irrigate both night and day since they are only allowed to use the water for a stated period. Where night irrigation is practised either from choice or necessity it is of great advantage to have the field thoroughly leveled and lath boxes, tubes or other devices in the ditches to feed the water to the furrows in small uniform streams.

HARVESTING.—The harvesting, like the planting and cultivation of sugar beets, is done under the supervision of the sugar companies. About the time the beets are maturing the field agents of the factory take a number of beets from various parts of the field and have them tested for purity and sugar contents. If they are found to meet the requirements, orders are issued to the grower to harvest the crop.

If the ground is soft enough to permit, a beet puller is used to plow out the beets. This consists of two prongs which run one on either side of the row close to the beets. This raises and loosens the beets so that they can be easily freed from the soil. If the ground is hard a beet plow is used, an implement somewhat like a subsoil plow. After these implements come a crew of men who gather the beets into windrows or piles, cut off the tops at the point of the lowest leaf and pile them up preparatory to hauling to the dumps or factory. If the piles have to be left in the field over night the beet tops are thrown over them to protect them against possible damage from frost. As rapidly as possible the beets are hauled to the factory or loading station. Sometimes it is impossible to get cars fast enough to take care of the beets as they come in and provision is usually made in the contracts for piling beets at the loading station until cars can be obtained.

SILOING.—In northern Colorado, the beets when harvested faster than they can be consumed at the factory are delivered at the dumps or loading stations, weighed and dumped in large piles nearby. These piles are 8 to 10 feet high, and sometimes 150 feet wide and 200 feet long. No weather protection is provided. As previously stated, the growers receive 85 cents per ton extra for siloed beets.

In the season of 1924, the acreage of sugar beets contributary to the American Beet Sugar Company in the Arkansas Valley of Colorado was 18,400 acres which produced an average yield of 10.35 tons per acre of 17.50 per cent. purity and yielded 3,600 pounds of sugar per acre.

COST OF GROWING.—In 1924, Parshall obtained cost data pertaining to the growing of sugar beets from farmers located in different parts of the Arkansas Valley in Colorado and the total cost varied from a maximum of $52.75 per acre to a minimum of

$44 and averaged $47.65 per acre. The average of each item is given below:

Preparation of land:	
Plowing	$3.53
Harrowing	1.16
Levelling	1.43
Rolling	0.44
Seed and planting:	
Seed 12 pounds per acre	3.00
Planting	0.54
Cultivation and furrowing	3.87
Hand labor for season	18.88
Irrigation 3 to 5 times:	
Labor in irrigating	2.67
Making field laterals	0.53
Harvesting:	
Plowing out	2.78
Siloing, 20 per cent. of crop	0.57
Hauling to beet dump	8.25
Total cost per acre	$47.65

47. Irrigation of Orchards.—In 1914, the writer prepared an article on this subject which was published as *Farmers' Bull.* 404 of the U. S. Department of Agriculture, and revised in 1917. The more important features of this publication are reproduced in this article with such modifications and additions as later experience seem to warrant.

Practically all the orchards both deciduous and citrus of the West are irrigated. On the Pacific Coast, particularly in California, the revenue derived from fruit forms a large part of the total revenue from soil products. In 1919 the fruit produced in California was valued at $234,613,000 or more than one-half of the total agricultural returns of the state. In that year the deciduous fruit was valued at approximately $159,000,000 and the citrus at less than $76,000,000

Selection of Land.—Care and good judgment should be exercised in the selection of an orchard tract. If it turns out well the profits are high, but if it fails the losses are heavy. It involves the setting aside of good land, the use of irrigation water and somewhat heavy expenses in purchasing trees, setting them out and caring for them until they begin to bear.

Assuming that the climate and soil of the district selected are adapted to the kind of trees to be grown, the next most important things to consider are good drainage and freedom from early and late frosts. Low-lying lands under a new irrigation system should be regarded with suspicion, even if the subsoil is quite dry at the time of planting. The results of a few years of heavy and careless irrigation on the higher lands adjacent may render the lowlands unfit for orchards. On the other hand, the higher lands are not always well drained naturally. A bank of clay extending across a slope may intercept percolating water and raise it near the surface. Favored locations for orchards in the mountain states are often found in the narrow river valleys at the mouths of canyons. The coarse soil of these deltas, the steep slopes and the daily occurrence of winds which blow first out of the canyons and then back into them, afford excellent conditions for the production of highly flavored fruits at the minimum risk of being injured by frost.

Proper exposure is another important factor. In the warmer regions of the West and Southwest a northern exposure is sometimes best, but as a rule the orchards of the West require warmth and sunshine, and a southerly exposure is usually more desirable. Natural barriers frequently intercept the sweep of cold, destructive winds, and when these are lacking, windbreaks may be planted to serve the same purpose. Depressions or sheltered coves should be avoided if the cold air has a tendency to collect in them, a free circulation of air being necessary to drive away frost. The low-lying lands seem to be the most subject to cold, stagnant air.

While experience has shown that orchard trees of nearly all kinds can be successfully grown on soils that differ widely in their mechanical and chemical composition, it has also shown that certain types of soils are best adapted to particular kinds of trees. Thus the best peach, almond, apricot and olive orchards of the West are found on the lighter or sandier loams; the best apple, cherry and pear orchards on heavier loams; while walnut, prune, and orange orchards do best on medium grades of soil. The requirements of all, however, are a deep, rich, and well-drained soil.

Grading the Surface.—As a rule fruit trees are planted on lands previously cultivated and cropped. One of the best pre-

paratory crops for orchards is alfalfa. This vigorous plant breaks up the soil and subsoil by its roots, collects and stores valuable plant foods, and when it is turned under at the end of the second or third year leaves the soil in much better condition for the retention of moisture and the growth of young trees.

An effort should be made to establish a fairly uniform grade from top to bottom of each tract. This is done by cutting off the high points and depositing the earth thus obtained in the depressions. The length of the furrows should not exceed one-eighth of a mile and in sandy soil they should be shorter. As a rule, it is not difficult to grade the surface of an orchard so that small streams of water will readily flow in furrows from top to bottom.

The practice of planting orchard trees on steep hillsides on a water grade is now well established. Such locations have good air drainage as a rule and the risk from damage to fruit by frost is less than on more level ground plantings. The rectangular method of setting out trees is not well adapted to steep slopes. In setting out trees on grade lines, the grade should vary from 1 to 2 per cent. in light soils and 0.5 to 3 per cent. in heavy soils. Thus the fall or rise, as the case may be, between any two trees 24 feet apart in the same row should be about 4 1/2 inches, in light soils.

Time of Irrigation.—It is difficult to find out when a mature orchard is in need of water. This uncertainty is in part due to the depth and spread of the roots and to the further fact that the soil around the deeper roots can only be judged by an examination of the cores of holes made by an auger, or soil tube. While it is true that the greater part of the roots of deciduous orchard trees are found within 6 feet of the surface, a few roots usually penetrate the subsoil under right conditions to double and triple this distance. These may be termed the life-insurance roots of the tree since they not only keep it alive during severe droughts but may enable it to produce a profitable crop of fruit when the moisture content of the 6-foot top layer drops below the wilting point.

In valuable orchards the proper time to apply water should not be determined solely by the appearance of the tree, particu-

larly its foliage. The grower should find out, if possible, the moisture content of the soil in the root zone. This is not easy on account of the wide variety of soils and their water holding capacities. In matters of this kind the Director of the State Agricultural Experiment Station may be consulted. He should know the wilting point of the soil in question and the quantity of water it will retain after an irrigation. The task of the grower when in possession of this information is to maintain a soil moisture content within these limits.

Applying Water.—Orchards are irrigated for the most part from furrows. The manner in which water is distributed from head ditches or pipes to furrows and the location, spacing and depth of furrows were described under Furrow Irrigation. Practice differs as to the amount of water which is turned into each furrow and the number of hours it is permitted to flow.

In southern California a miner's inch of water (1/50 second-foot) is usually allowed to run in each furrow until the soil is moistened to a sufficient depth. The heads used vary from 30 to 60 miner's inches.

In the Payette Valley, Idaho, 200 or more miner's inches are turned into the head ditch and divided up by means of wooden spouts into a like number of furrows. On steep ground much smaller streams are used. The length of the furrow varies from 300 feet on steep slopes to 600 feet and more on flat slopes. The time required to moisten the soil depends on the length of the furrow and the nature of the soil. In this locality it varies from 3 to 36 hours.

J. H. Foreman owns 20 acres of bearing orchard under the Sunnyside Canal in the Yakima Valley, Washington, and waters it four times in each season with 14 miner's inches (0.35 cubic foot per second). He makes three furrows between the rows, which are 40 rods long. The total supply is applied to one-half the orchard (10 acres) and kept on 48 hours.

On the clayey loams of the apple orchards on the east bench of the Bitter Root River, Montana, it requires from 12 to 18 hours to moisten the soil in furrow irrigation 4 feet deep.

In irrigating the deciduous orchards in the Sierra foothills of Placer County, California, very small heads are required in order to prevent erosion on the steep slopes. The continuous flow of 3

to 4 miner's inches is sufficient for a 20-acre orchard during the irrigation season which extends from May 1 to Oct. 1. As a rule, there is but one furrow for each row of trees. This may extend down the steepest slope encircling the upper half of each tree in its course or it may extend in a diagonal direction. A tiny stream no larger, on steep slopes, than a pencil is permitted to run for 24 to 48 hours and is then changed to another furrow.

Number of Irrigations.—For nearly half the entire year the fruit trees of Wyoming and Montana have little active, visible growth, whereas is the citrus districts of California and Arizona the growth is continuous. A tree when dormant gives off moisture, but the amount evaporated from both soil and tree in winter is relatively small, owing to the low temperature, the lack of foliage and feeble growth. A heavy rain which saturates the soil below the usual covering of soil mulch may take the place of one artificial watering, but the light shower frequently does more harm than good. The number of irrigations likewise depends on the capacity of the soil to hold water. If it readily parts with its moisture, light but frequent applications will produce the best results, but if it holds water well a heavy application at longer intervals is best, especially when loss by evaporation from the soil is prevented by the use of a deep soil mulch.

In the Yakima and Wenatchee fruit-growing districts of Washington the first irrigation is usually given in April or early in May. Then follow three to four waterings at intervals of 20 to 30 days. At Montrose, Colo. water is used three to five times in a season. At Payette, Idaho, the same number of irrigations is applied, beginning about June 1 in ordinary seasons and repeating the operation at the end of 30-day intervals. As a rule, the orchards at Lewiston, Idaho, are watered three times, beginning about June 15. From two to four waterings suffice for fruit trees in the vicinity of Boulder, Colo. The last irrigation is given on or before Sept. 5, so that the new wood may have a chance to mature before heavy freezes occur. In the Bitter Root Valley, Montana, young trees are irrigated earlier and oftener than mature trees. Trees in bearing are, as a rule, irrigated about July 15, Aug. 10, and Aug. 20 of each year. In San Diego County, California, citrus trees are watered six to eight times, and deciduous

trees three to four times in a season. In Placer County, California, deciduous trees are watered every 2 weeks.

Duty of Water.—The duty of water for 1 acre as fixed by water contracts varies all the way from one-fortieth to one-four-hundredth of a cubic foot per second. In general, the most water is applied in districts that require the least. Wherever water is cheap and abundant the tendency seems to be to use large quantities, regardless of the requirements of the fruit trees. In Wyoming the duty of water is seldom less than at the rate of a cubic foot per second for 70 acres. In parts of southern California the same quantity of water not infrequently serves 400 acres, yet the amount required by the fruit trees of the latter locality is far in excess of that of the former.

In recent years the tendency all over the West is toward a more economical use of water, and even in localities where water for irrigation is still reasonably low in price it is rare that more than 2 1/2 acre-feet per acre are applied in a season. This is the duty provided for in the contracts of the Bitter Root Valley Irrigation Company, of Montana, which has 40,000 acres of fruit lands under ditch. Since, however, the water user is not entitled to receive more than one-half of an acre-foot per acre in any one calendar month, it is only when the growing season is long and dry that he requires the full amount.

In the vicinity of Boulder, Colo., the continuous flow of a cubic foot per second for 105 days serves about 112 acres of all kinds of crops. This amount of water, if none were lost, would cover each acre to a depth of 1.9 feet. In other words, the duty of water is a trifle less than 2 acre-feet per acre.

The depth of water used on a 21 1/2-acre apple orchard at Wenatchee, Wash., was measured and found to be 23 inches. The trees were 7 years old and produced heavily. This orchard was watered five times, the first on May 13 and the last on Sept. 23. In San Diego County, California, 1 miner's inch (1/50 second-foot) irrigates from 6 to 7 acres near the coast where the air is cool and evaporation low, but 20 miles or so inland the same amount of water is needed for about 4 acres.

On the sandy loam orchards of Orange County, California, it has been demonstrated that 2 acre-inches every 60 days are sufficient to keep bearing trees in good condition. The rainfall

in this locality averages somewhat less than 12 inches per annum, but about 95 per cent. of the total falls between November and May, inclusive.

The most reliable and in many ways the most valuable records pertaining to duty of water on orchards have been obtained by the water companies of Riverside County, California. Here more or less irrigation water is used every month of the year. Figure 97 is a graphic representation of the average amount of water used per month in a period of 7 years by the Riverside

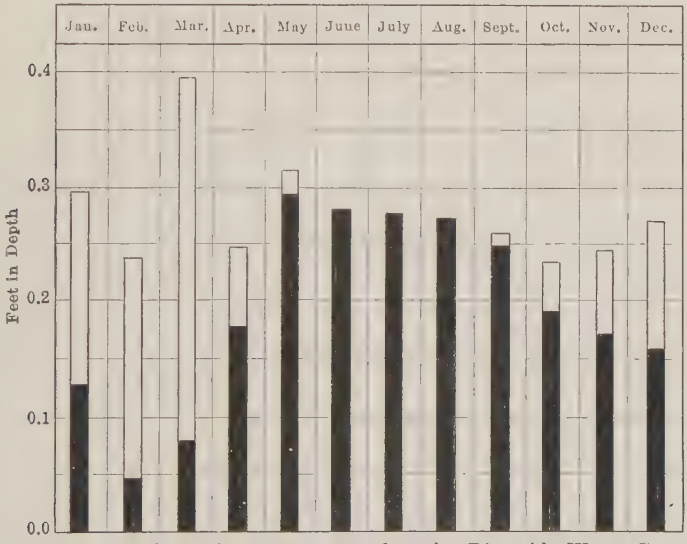


FIG. 97.—Average duty of water per month under Riverside Water Company, Dec. 1, 1901, to Nov. 30, 1908.

Water Company in irrigating about 9,000 acres, of which nearly 6,000 acres are planted to oranges and the balance to alfalfa. The figures given in the diagram represent depth in feet over the surface watered. In the following table is given the average duty of water per month in acre-feet per acre under the same system from Dec. 1, 1901, to Nov. 30, 1908, a period of 7 years. The table also includes the average monthly rainfall at Riverside, Calif., for the same period and adding the quantity of water applied in irrigation in any one month to the rainfall of that month gives the total moisture received by the soil.

TABLE NO. 46.—WATER USED UNDER RIVERSIDE WATER COMPANY'S SYSTEM, 1901–1908

Month	Average depth per acre, feet	Average rainfall, feet	Total water applied, feet	Month	Average depth per acre, feet	Average rainfall, feet	Total water applied, feet
December	0.159	0.109	0.268	July	0.272	0.002	0.274
January	0.123	0.170	0.293	August	0.269	.....	0.269
February	0.046	0.190	0.236	September	0.243	0.015	0.258
March	0.078	0.316	0.394	October	0.189	0.043	0.232
April	0.177	0.068	0.245	November	0.169	0.073	0.242
May	0.291	0.023	0.314				
June	0.274	0.003	0.277	Total	2.29	1.01	3.30

INTERCROPPING.—The large majority of California fruit growers do not grow marketable crops between the trees. They believe in clean culture, except where leguminous crops are used to renovate and fertilize the soil. From the standpoint of the large commercial orchard and the well-to-do proprietor, this practice has much to recommend it.

The settler on a small tract set out to young trees cannot afford, if his means are limited, to wait 4 or 5 years for the first returns. He must produce crops between the rows, and the question for him to consider is how this can be done with the least possible injury to the trees. A plentiful supply of water and a deep rich soil are the essentials of intercropping. In most of the fruit districts of the West water for irrigation is still reasonably low in price, and the extra amount required for intercropping represents but a small part of the net gains from such crops.

Shallow-rooted plants are considered the most desirable for this purpose. Beans, melons, sweet potatoes, tomatoes and peanuts are the most common in California. The cultivation is done with one horse and a small cultivator. A clear space 3 to 4 feet wide is left on each side of the young trees. In the Verde River Valley of Arizona, strawberries, lettuce, onions and melons are raised in the young orchards. In parts of Idaho, alfalfa fields are frequently plowed under to plant trees. When this is done, berries, beans, melons, onions and tomatoes can be grown between the rows for several years without any apparent injury to young trees. In northern Colorado, raspberries, gooseberries, currants, as well as corn, beans and peas are often planted

in orchards, while in southwestern Kansas the order is usually cabbage, melons and sweet potatoes.

In the young apple orchards of Hood River Valley, Oregon, strawberries are frequently planted between the rows. The manager of a large apple orchard company in Montana states that no appreciable effect is noticed on apple trees as a result of growing potatoes, cabbage, beans, onions and other vegetables between the trees providing the intercrops are well cultivated and irrigated. In the fruit districts of Washington, intercropping is a common practice.

While opinions differ regarding the wisdom of growing such crops as have been named between the tree rows, most fruit growers are convinced of the beneficial effects of cover crops. Notwithstanding the scarcity and high value of water in the Riverside citrus district, the superintendent of a large fruit company has for years grown peas and vetch in the orange and lemon orchards under his management, and advocates the free use of irrigation water to supplement the winter rains for the rapid and vigorous growth of such crops. In the walnut groves of Orange County, California, burr clover is sown in the fall, given one or two irrigations during the winter if the rainfall is below the normal and plowed under in April.

The cost of such cover crops as peas, vetch or clover includes the seed, the labor of sowing it, the water, and the time required to apply it. These items, according to Dr. S. S. Twombly, of Fullerton, Calif., amount to from $2.50 to $3.25 per acre. Twenty tons per acre of green material is perhaps an average crop. In this tonnage there would be about 160 pounds of nitrogen, which at 20 cents per pound represents a value of $32 per acre for a cover crop like vetch.

Intercrops and orchard trees usually differ in their water requirements and in the time and frequency of irrigation. M. B. Williams, engineer and horticulturist, in supervising the subdivision of several large estates in the vicinity of Yuba, Calif., has devised a plan of separate irrigation for the two crops. By means of a 30-horsepower tractor, steel ridger and wooden follower shown in Fig. 98 he makes ridges on each side of the young orchard trees which enclose a strip 4 feet wide. This strip with the trees in the center can be watered by flooding as in the Border Method

(Art. 21) independently of the watering of the sugar beets which are grown between the tree rows.

Winter Irrigation.—When water is used outside of the regular irrigation period, or what is in many cases equivalent, outside of the growing season, it is termed winter irrigation. Over a large part of the arid region the growing season is limited by low temperatures to 150 days, or less, and when the flow of streams is utilized only during this period much valuable water runs to waste.

It was for the purpose of utilizing some of this waste that the orchardists of the Pacific Coast states and Arizona began the

Fig. 98.—Steel ridger and wooden follower drawn by 30 H. P. factor.

practice of winter irrigation. The precipitation usually occurs in winter in the form of rain, and large quantities of creek water are then available. This water is spread over the orchards in January, February, and March, when deciduous trees are dormant. The most favorable conditions for this practice are a mild winter climate; a deep, retentive soil which will hold a part of the water applied; deep-rooted trees; and a soil moist from frequent rains.

In the colder parts of the arid region winter irrigation is likewise being practised with satisfactory results. The purpose is not only to store water in the soil but to prevent the winter killing of trees. Experience has shown that it is not best to

apply much water to orchards during the latter part of the growing season, since it tends to produce immature growth which is easily damaged by frost. In many of the orchards of Montana no water is applied in summer irrigation after Aug. 20. Owing, however, to the prevalence of warm chinook winds, which not only melt the snow in a night, but rob the exposed soil of much of its moisture, one or two irrigations are frequently necessary in midwinter.

48. Irrigation of Rice in the Gulf States.[1]—Practically all of the rice grown in this country is irrigated. In 1919 according to the census, the acreage irrigated was 892,761 acres which produced 35,032,275 bushels valued at $96,368,000.

In 1896, the forerunner of the modern pumping plant for the irrigation of rice was operated for the first time near Crowley, La., marking the beginning of a new era in the development of irrigated rice in this country. Largely as a result of better facilities for securing and controlling an adequate water supply, the yield of cleaned rice increased from 116,000,000 pounds in 1897 to 520,000,000 pounds in 1907.

Irrigated rice, to be profitable, requires the right kind of soil and subsoil, a suitable climate, and an adequate water supply. Any rich loam or clay soil that is level enough to be economically irrigated, if underlaid with a compact clay subsoil, impervious to water, is suitable for rice culture. If the land is rolling or broken, water cannot be easily kept on it, and if the subsoil is loose, there will be such a loss of water that irrigation will be very expensive. Not more than two successive rice crops can be grown profitably on very sandy loam soil. The crop must likewise have at least 4 months of warm weather and no cool nights during heading time.

The water used in rice irrigation is derived from streams, lakes, bayous, and wells. More than 97 per cent. of the water used is pumped and over one-quarter of this is pumped from wells. A very small acreage is irrigated with stored water from wells, and a similar area with water stored in shallow reservoirs and allowed to flow to rice planted on lower land. Sometimes rice planted on low land receives its irrigation from the inflow of water from

[1] Extracted in part from published and unpublished reports of C. G. Haskell.

surrounding higher fields. This is the so-called "Providence" method. Along the Atlantic coast several thousand acres of rice are grown on low land near the mouths of rivers and are irrigated by fresh river water backed up over it during high tides.

Preparation of Land, Planting and Seeding.—On the prairies the land is generally plowed with sulky or gang plows. Along the Mississippi River and the Atlantic coast where negro laborers do most of the work the walking plow is generally used. The land is disked and harrowed to make a good seed-bed and the rice is planted with a drill or sometimes with a broadcast seeder. Along the Atlantic coast the rows are made 15 inches apart to allow the rice to be cultivated, but in all other sections rice is not cultivated and the rows are made about 7 inches apart.

In Louisiana, Texas and Arkansas, Honduras and Shinriki (Japan) rices are the principal varieties grown for commercial purposes, although during the last few years several varieties have been developed in this country which do better than the imported rices. The Honduras is a tall rice with coarse stalks and wide leaves. The heads and the grains in the heads hang long and are light colored. The Japan rice is short with small wire-like stalks and narrow leaves. The head and grains are shorter than the Honduras rice. By reason of the large number of heads per plant, Japan rice makes larger yields than the Honduras, but it does not bring as high a price on the market. On the Atlantic coast the famous Carolina Gold Seed and white rice are grown. The Gold Seed is about the size of the Honduras rice and is known by the golden color of the hulls. About 90 pounds of Honduras or 65 pounds of Japan rice are generally planted to the acre.

Canals, Pumping Plants and Laterals.—The irrigation canals which carry the water from the streams and lakes to the lands to be irrigated are built on high ground and sometimes extend 30 miles from their source. The larger canals are merely two parallel levees built upon the surface of the ground from 200 to 275 feet apart, and since their grades are very flat they are really long reservoirs in which water flows very slowly. The slow velocity causes little loss of head and keeps the total lift at the pumping plant at a minimum. This is essential, for the cost of the water depends largely upon the height to which it is elevated.

From the main canals the water is conveyed to the fields in laterals.

Some of the largest and best equipped pumping plants in the world pump into irrigation canals from the streams of southwestern Louisiana and southeastern Texas. They are frequently equipped with large horizontal centrifugal or rotary pumps, operated by compound condensing Corliss engines. Steam is generally supplied from horizontal water-tube boilers and petroleum is often used for fuel.

Wells.—A large part of the land upon which rice is grown is underlaid with water-bearing beds of sand and gravel at depths varying from 40 to 1,000 feet. Great improvements have been made during recent years in methods of drilling and equipping wells. Practically all of the water obtained from wells is pumped. The average of the discharges from over 800 wells in Texas, Arkansas and Louisiana is 950 gallons per minute. Some wells supply as high as 3,000 gallons per minute and irrigate about 400 acres of rice. Irrigation water from wells enables much land to be planted to rice which is out of reach of the river, bayou or lake canals and could not otherwise be irrigated. The greater part of the irrigation development in the rice country during recent years has been along the line of irrigation from wells.

Field Levees.—High levees are built around the field to prevent the escape of water. Other levees are built across the field on contours to hold the water on the land. A contour field levee is built on the surface of the ground for every drop of three-tenths of a foot. Sometimes the levees are located on every two- or four-tenths of a foot drop. The field is thus divided into irregular-shaped cuts depending in size upon the slope of the ground. All the land in each cut is of nearly the same elevation. Figure 99 shows a wooden "push" that is generally used to build levees and to dig small drainage ditches.

In the newer or more up-to-date rice farms the cross-levees are built wide so that teams can work them and rice can be grown upon them. Figure 100 shows a cross-section of a common, narrow, high, field levee. Figure 101 shows a cross-section of a low, wide, field levee.

Structures to Control the Flow of Water on Fields.—Drainage ditches are provided so that water can be removed

from any cut, when desired. If the soil is loose, sandy loam, wooden gates are placed in the field levees to regulate the flow of the water and to prevent the levees washing out. Sometimes a sack is placed so that the water can flow over it to answer the purpose of a gate. The lateral, or small canal, which carries the

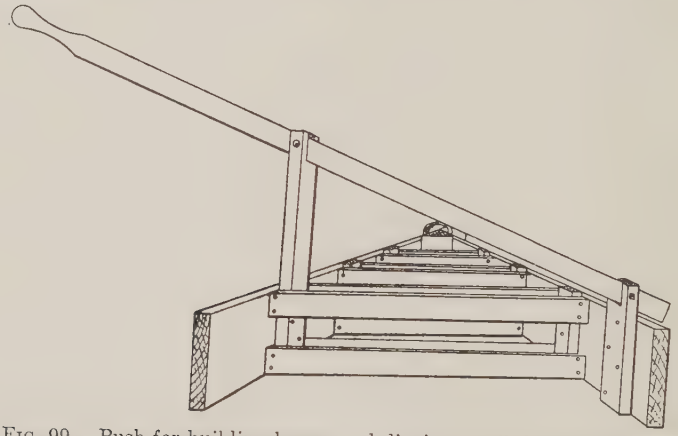


FIG. 99.—Push for building levees and digging small drainage ditches.

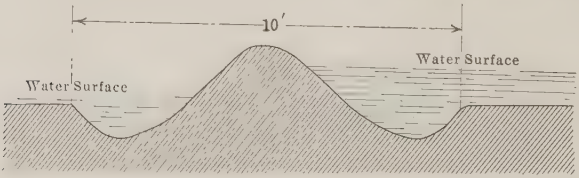


FIG. 100.—Cross-section of the common high field levee.

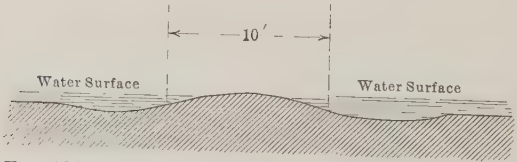


FIG. 101.—Cross-section of the low, wide field levee.

water supply should be built along the side of the field so that water can be applied to any cut without flooding those above it. If the field is very large and the cuts are long, the lateral should be extended down the slope dividing the cuts so that the water will not have to flow too far to reach the farther ends of the cuts.

Securing Water for Irrigation along the Mississippi.—Along the Mississippi River rice grows on alluvial land just over the levees. When the crop was first introduced into this section the planters cut the levees which protect the land along the river from overflow to get water to irrigate their rice or placed wooden gates or iron pipes in the levees to allow the water to flow from the river to their fields. After several crevasses and overflows resulted from this practice, a law was passed preventing the cutting of the levees. This made it necessary to syphon the water over them. As long as the river is low the water has to be pumped into a reservoir built beside the levee, and of sufficient height to cause the water to flow from it through the syphon to the field.

Small portable pumping plants are used to pump the water from the river into the reservoirs. During the seasons when the river is high, irrigation water is very cheap but when the river is low it is very expensive. On the Mississippi River above Baton Rouge, La., the fields are laid out and irrigated in much the same way as on the prairie lands. Below Baton Rouge the older method is still practised.

Some idea of the arrangement of field levees and ditches in different parts of the rice area may be obtained from the following outline:

The land along the Mississippi River slopes back to the swamp or low land. Parallel drain ditches are dug down this slope at distances varying from 200 to 600 feet apart. Levees are built along the sides of the ditches and cross-levees at right angles to them for every drop of two- to five-tenths of a foot in the surface of the land. The cross-levees thus range from 50 to 800 feet apart and form rectangular cuts of varying sizes. The water is allowed to flow from cut to cut across the field; and when the field is to be drained, the water is allowed to flow off through the drainage ditches.

Application of Water.—Irrigation water is applied to the land when the rice is 4 inches above the surface. If the water is held deep when the rice is young, it will cause the plants to grow tall and slender at a rapid rate and not to thicken up or stool out to make many heads to each plant. If the weather is very hot, the water must be held not less than 1 inch and

preferably 2 inches deep or it will become hot enough to scald the young rice. There is little danger of the water getting hot enough to injure the early planted rice but rice planted late in the season should be watched carefully.

After the rice has grown enough to shade the water there is no danger of scalding and the water may be allowed to get lower if desired. During cool weather the water should be held from 1 to 2 inches deep on the land in order that the sun may warm it quickly in the morning and the plants be given a chance to grow. After the rice has stooled properly in shallow water the water is held at an average of 4 inches or more on the cuts. The average depth of water on a cut is the depth midway between properly located contour levees. Tests to determine the depth of water which will cause the greatest yields have shown that for old, grassy fields the yields increase with the average depth of water up to 6 inches and probably beyond. It is also true that the increase in yield is very slight for average depths greater than 4 inches. It is therefore not economical to flood deeper because it would require the use of a greater amount of water and the building of higher field levees. New land does not require as deep flooding as old land.

Duty of Water, Rainfall and Evaporation.—Measurements have been made of rainfall, evaporation, and the duty of water for irrigating rice on prairie lands of Louisiana, Texas and Arkansas for 11 years, during which 21 measurements have been made. The averages of these measurements give 15.74 inches of pumped water and 17.16 inches of rainfall applied to the land and a loss due to evaporation from flooded rice fields of 15.33 inches. The total average depth of water applied was 32.90 inches. Subtracting the evaporation from this leaves 17.57 inches which was used by the plants, percolated into the ground and escaped through the outside field levees. Allowing time for break-down of pumping plant and for stoppage of pumping when irrigation water is not needed after rains, the duty of water for rice irrigation for prairie land runs from 7 1/2 to 8 gallons per minute per acre, depending upon the character of the land and the distance the water has to be carried in the canal. If the water is pumped at the field so that there is no loss in a canal, less water will be required. For the black clay and loam soils along rivers,

like that along the Mississippi River, 10 gallons of water per minute per acre should be provided while if the land has a loose subsoil and is located near a river or lake, 38 to 40 gallons will be needed.

In Texas, Arkansas and all of Louisiana, except the strip along the Mississippi River below Baton Rouge, the water has to be drained from the field in time for the land to become dry enough to support teams and binders at harvest time. This requires from 8 to 14 days according to the character of the land and the time required for the water to drain from the field. Generally the water is removed when most of the heads of the rice are in the dough stage, the end grains have begun to harden and the heads have turned yellow and filled enough so that most of them have turned down.

Along the lower part of the Mississippi River and the Atlantic coast where the rice is still cut with sickles, the water is left longer on the field, and in some cases is drained off only the day before the rice is cut. In all sections the bundles of rice are shocked on the field and threshed by threshing machines driven by steam or gasoline engines.

Marketing.—Rice is generally sold to the rice mills through buyers who go over the country during threshing time to sample the rice. Frequently several buyers bid on the same rice. During recent years the rice buyers have organized a sales company called the Southern Rice Growers Association, the object of which is to give stability to the rice market and protect the growers by regulating the price, grading the rice and selling it for the highest possible price, under the greatest competition from the buyers. The rice growers sign a contract agreeing not to sell their rice for less than the price fixed for that grade of rice by the association. In consideration of the assistance of the association in selling the rice and to provide a fund to be used to increase the consumption of rice, each member of the association pays into its treasury 7 cents a sack when his rice is sold.

Irrigation of Rice in California.[1]—Rice was introduced in California as early as 1860. That year a number of small

[1] From report of C. F. Dunshee in charge of rice investigations, University of California, February, 1925.

plantings were made in several counties, the whole crop, however, amounting to only 2,410 pounds. In 1862, the state legislature offered the following premiums: $250 for the first 1,000 pounds of rice; $500 for the first 5,000 pounds; $1,000 for the first 10,000 pounds. This offer was repeated during the 3 succeeding years, but even with these financial inducements no interest was shown in the industry. It was not until 1912, after 3 years of experimental work by the U. S. Department of Agriculture, that the first commercial planting was made on 1,400 acres. This venture proved so successful that the acreage was materially increased during the following years, the peak being reached in 1920 with 162,000 acres in crop. In 1921, with 135,000 acres in rice, California ranked second among the rice-producing states, Louisiana being first.

The following table will give some idea of the growth of the industry and the value of the crop.

TABLE NO. 47

Year	Acreage	Production, bushels		Farm value Dec. 1
		Per acre	Total	
1912	1,400	50.0	70,000	$ 64,000
1913	6,100	48.00	293,000	293,000
1914	15,000	53.3	800,000	800,000
1915	34,000	66.7	2,268,000	2,041,000
1916	55,300	59.0	3,263,000	2,545,000
1917	80,000	68.0	5,440,000	9,520,000
1918	106,000	66.0	7,011,000	13,321,000
1919	142,000	60.0	8,520,000	22,748,000
1920	162,000	51.0	8,262,000	9,997,000
1921	135,000	54.0	7,290,000	8,384,000
1922	140,000	55.0	7,700,000	8,470,000
1923	106,000	51.6	5,470,000	6,126,000
1924	88,000	51.1	4,497,000	7,465,000

Soil Requirements.—The large amount of water required for rice under the most ideal conditions practically limits the production to the heavy clay or clay adobe soils, which are underlaid with an impervious subsoil. Due to the high prices received for

rice during 1917, 1918, and 1919, a large acreage was planted on the loam and silt soils. The low duty of water, often 10 acre-feet per acre, and the damage resulting to adjacent lands by a rising water table, has made the production of rice on these soils under ordinary price conditions not economical.

At the present time (1925) the rice-producing area is mainly confined to the low, level soils of the Sacramento Valley, in the counties of Butte, Colusa, Glenn, Sutter and Yolo. There is a considerable area in the San Joaquin Valley that is well adapted to rice growing, the lack of water being the one factor that has delayed production there.

Duty of Water.—Measurements of the amount of water required for the production of rice, carried over several years on a large number of fields, show that for the clay and clay-adobe soils a net duty of 5 acre-feet per acre is ample. Certain fields have shown a net duty as high as 4 acre-feet per acre.

Water Supply and Drainage.—Practically all of the water for rice irrigation is derived from the Sacramento and Feather rivers. The Sacramento River supplies approximately 75 per cent. of the water used for this purpose. The water is pumped from the rivers into canals, many of which carry the water long distances before all of it is applied to the fields. One canal, capable of supplying water to 40,000 acres of rice is nearly 40 miles long.

Some fields have been supplied with irrigation water pumped from wells. The cost of water obtained in this way is usually so high that this source of supply is rarely used.

During the early years of the industry little attention was paid to drainage. As the water table began to rise, in some cases nearly to the surface of the soil, however, it became apparent that adequate drains must be constructed if the industry was to survive. In most sections of the rice area, drains from 4 to 10 feet deep have been dug to carry the excess water and seepage from the rice fields to the Sacramento River. During seasons of deficient water supply many of these drains are dammed and the water lifted back on to the rice fields.

Preparation of Land.—On land that is being prepared for rice for the first time, the entire area to be planted is usually plowed with gang plows. The soil is then worked into a fine seed-bed with the aid of discs and large drags. When the seed-bed is

ready the practice is either to broadcast the seed at the rate of 110 to 135 pounds to the acre, or seed with a drill. If a drill is used, 5 to 10 pounds less seed per acre is planted. Drilling seed is slow, uniform, and expensive, while broadcasting is rapid, not uniform, and inexpensive. Following the seeding, the land is surveyed for levees (Fig. 102) which are run on a contour interval of from two- to three-tenths of a foot. A man with a plow usually follows the rod man to mark the location of the levees. A gang plow follows this plow mark, plowing a strip about 15 feet wide. After this operation a large checker is pulled along the contour crowding the loose dirt up into a high, narrow levee.

FIG. 102.—Flooding within rice levees, Sacramento Valley, California.

When all the contour levees are built in this manner, the checker is pulled around the margin of the field, throwing up the border levee, which should be higher and broader than the field levees. These levees are usually left standing from 3 to 4 years, or until they become foul or have settled to such an extent that the proper depth of water cannot be maintained. During these years plowing is done between the levees. At harvest time the binder drivers cut each area separately, never attempting to cut back and forth across the levees.

Rice Varieties.—The Japanese type of rice is grown almost exclusively in California. This is a short grain, non-glutinous type of rice that meets with special favor with the Japanese, and is the type that is grown in Japan. The long-or medium-

grain rices have been grown in California, but without any great commercial success. The majority of the rice grown in California is marketed in the Hawaiian Islands and Japan. The people in the United States have learned to eat the long-or medium-grain rices and demand but comparatively small amounts of the short-grain type.

Methods of Irrigation.—The method of irrigation used depends upon whether the field to be irrigated is free from weed seeds, particularly "barnyard grass" (*Echinochloa crus-galli*). If the field has been in rice not more than 1 to 3 years it is usually comparatively free from these weeds, and the seed is drilled or broadcasted and harrowed into the soil. Water is turned on the field as soon as seeding is completed, in sufficient quantity to thoroughly wet the soil, any excess water being drained. This procedure is repeated several times, until the plant has been out of the soil for about 30 days. In normal years this will be about June 15. The number of irrigations depends on the soil and climatic conditions, the general practice being to keep the soil damp during this period. The water from the last irrigation is not drained, but is gradually raised until the average depth over the field is about 6 inches. This depth is maintained until the water is drained from the field in the fall.

This method of irrigation is particularly favorable to the growth of barnyard grass, and on "new" land the wise operator will keep these weeds pulled. The general experience, however, has been that when the cost of weeding exceeds $5 per acre it is not economical to keep the field clean. On new land this method can be followed for about 3 years before the weed growth prohibits the growing of a profitable crop. Previous to 1920, no method was known of controlling the barnyard grass, and when profitable crops could no longer be grown, the fields were abandoned and clean land obtained. Finally the limit to the available clean land was reached and it became necessary to find some way of controlling the weed pests.

A number of growers discovered that the barnyard grass would not grow through water as deep as 6 inches. They also discovered that rice seed would germinate and grow through this depth of water and produce a profitable crop on foul land. The practice on foul land, therefore, is to prepare a very fine seed-bed,

and broadcast the seed, without harrowing it into the soil, at the rate of about 150 pounds per acre. Water is immediately turned on to the field and brought to a depth of about 6 inches and kept there throughout the season. It is essential that none of the seed be covered with soil, and for this reason best results are always obtained by preparing a fine seed-bed.

The proper time to drain a rice field depends upon so many varying factors that no definite rule can be given. The grower endeavors to drain the water sufficiently in advance of the maturity of the crop so that by the time the ground is dry enough to support the stock and binders, the rice will be ready to cut.

Fig. 103.—Levee boxes in rice irrigation.

Naturally, soil, probable climatic conditions, water table and surface drainage all have to be taken into consideration.

Field ditches are constructed along the upper side of the field so that the water can enter the high corner and also can be run to any check without having to go through the rest of the field.

Boxes (Fig. 103) are placed in each levee to regulate the flow of the water and to aid in draining in the fall.

It is customary to run a drain ditch along the lower side of the field and connect it with the main drainage system serving the community.

Cost of Production.—The cost of production varies from year to year according to the price of labor, stock and water.

It also depends to a marked extent on the weather conditions at harvest time. A wet fall may easily add $5 to $15 per acre to the cost of producing the crop. The costs given in Table No. 48 are only approximate. They are based on several years' observation in the field in contact with a large number of growers. It is assumed that the farmer rents the land, paying one-third of the crop as rent, the owner furnishing the water. The farmer owns his equipment, such as tractor, plows, disks, binders, thresher, wagons, etc.

TABLE No. 48

OPERATION	COST PER ACRE
Plowing	$3.00 to $4.00
Disking and dragging	1.50 to 2.00
Repair of levees	0.10 to 0.20
Repair of boxes	0.10 to 0.30
Seed	4.50 to 6.50
Care of crop from planting to harvest	3.00 to 4.00
Binding	3.00 to 7.00
Shocking	1.00 to 1.50
Binder twine	0.55 to 0.75
Depreciation, interest, etc	4.50 to 8.00
	$21.25 to $34.25

Threshing and miscellaneous expense

	COST PER 100-POUND SACK
Threshing	$0.25 to $0.50
Sacks	0.09 to 0.12
Sack twine	0.01 to 0.01
Banking out	0.02 to 0.03
Trucking to warehouse	0.05 to 0.10
Warehousing	0.10 to 0.10
Marketing	0.05 to 0.06
	$0.57 $0.92

Table No. 49 gives the average yield in pounds per acre from 1912 to 1924 inclusive and the average price received for rice sold through the Rice Growers Association from 1921 to 1923 inclusive.

TABLE NO. 49

Year	Yield per acre, pounds	Average price per 100 pounds
1912	2,450	
1913	2,450	
1914	2,352	
1915	2,612	
1916	2,829	
1917	3,332	
1918	3,234	
1919	2,940	
1920	2,499	
1921	2,646	$2.675
1922	2,695	2.30
1923	2,528	2.81
1924		

A large part of the rice crop is marketed through the Rice Growers Association of California, a cooperative organization controlled by the growers. The object of the association is to stabilize the price and aid the growers in marketing the crop in an orderly way. The association keeps informed of the market conditions, and, while it does not set a price, the growers are advised to hold or sell as conditions seem to warrant. They have been very successful in stimulating foreign markets and in obtaining the highest possible price for the crop. Members of the association are aided in obtaining funds to finance their harvest operations. A charge of 5 cents is made on each 100 pounds of rice marketed through the association.

The growers who are not members of the association deal directly with the agents of the various mills in disposing of their crop.

49. Irrigation of Cotton.—Nearly three-fourths of the cotton produced in the world is grown in the United States. Cotton is also grown in India, Egypt, Asiatic Russia (Turkestan), China, Brazil, Peru, Mexico, Turkey and Persia. Cotton crops are artificially watered in Egypt, and Sudan, Africa, India, Algeria, Persia, Turkestan, Mexico, Peru and Brazil but the practice in this country is of recent origin. Cotton is produced in all of the southern boundary states from Georgia to California but only

in California, Arizona, New Mexico and southwest Texas is it necessary to apply moisture artificially to produce a commercial crop.

In 1908, there were less than 5,000 acres of irrigated cotton in the United States, while in 1919 the area had increased to 214,576 acres, producing cotton valued at $30,457,881.

The success of cotton growing under irrigation in the Southwest has been due in large measure to the splendid work of the scientists of the Bureau of Plant Industry, U. S. Department of Agriculture at their experiment stations at San Antonio, Sacaton, Yuma, Indio and Shafter.

The author is indebted to James C. Marr, Irrigation Engineer of the Division of Agricultural Engineering of the same Department for the irrigation features of this article.

Selection of Land.—Though large yields of cotton have been obtained on soils ranging from very heavy to very sandy soils, medium sandy loam has been found to give uniformly the best results. The reason for this is that it requires less skill to handle this type of soil properly. It is easily worked, does not bake or crack readily and holds moisture well.

Alkali and hardpan soils will not produce the best yields of cotton and are not recommended for that purpose excepting in cases where the crop is planted in connection with the reclamation of such land.

Subirrigated land, when free from alkali and hardpan, may produce record crops of cotton.

Old alfalfa or Bermuda sod are best for cotton when properly handled. It is more or less common belief among cotton growers that very fertile soils are not best for cotton, since large cotton stalks are likely to develop at the expense of fruitfulness, but it has been demonstrated repeatedly that under proper cultural methods and irrigation practice this tendency can be overcome.

Preparation of Land.—The field-irrigation system and fall of the land in the direction of irrigation should be such as to permit slow and even irrigation of the crop. With the possible exception of very sandy soil the fall should be nearly flat, or from 0.5 to 0.25 of a foot in 40 rods. Where necessary, bordered strips should be provided in order to eliminate all side slope. The

length of run best for most soils is about 40 rods, though for very sandy soils it should be less than this.

The best methods of preparing soil for planting depend upon so many factors that it is impossible briefly to cite the procedure that should be followed in each particular case. Under any given set of conditions the following results should be obtained:

1. Thorough aeration of the soil.
2. Eradication of alfalfa, Bermuda grass, weeds etc.
3. A good soil tilth.
4. A seed-bed thoroughly wetted to a depth of 5 or 6 feet with a fine shallow mulch on the surface.

It is not always necessary to plow cotton land every year in order to loosen and aerate the soil. Notably in Imperial Valley, California, and particularly in Imperial Valley, Mexico, satisfactory results have been obtained in fields where cotton follows cotton to alternate plowing one year with double listing the next. This practice reduces the cost of production.

Fields of old alfalfa and Bermuda grass sod should be plowed shallow early in the fall, left in that state for several months if possible, then plowed deep and harrowed and rolled or floated until in first-class tilth. If cotton is to be grown for 4 or 5 years in succession much can be accomplished in this first year of preparation that will aid in the years following.

An ideal moisture condition is procured easiest with sandy and sandy-loam soils. After plowing and immediately before planting a heavy irrigation is applied. This is followed as soon as the land is in condition by a light harrowing and possibly by floating or rolling. The land is then ready to be planted.

With heavy soils greater care is required to procure proper soil and soil-moisture conditions for seed germination and for satisfactory operation of the cotton planter. Though there are a number of variations in the practice of handling these soils, they may be grouped under two general classes, *i.e.*, those involving irrigation before planting and those where water is applied after planting. The former is preferable where it can be made to give satisfactory results. It consists of irrigating by the furrow method an otherwise well-prepared field and following this by a light cross-harrowing and sometimes by floating. The seed is then planted in the reduced ridges or beds. Harrowing is some-

times delayed until after the cotton is planted and up. The second practice consists of planting very shallow in dry, well-mulched soil and then irrigating either by the furrow method or by flooding between borders. When furrow irrigated, the land is planted flat; the cotton rows ridged up with a disc cultivator; and as soon as possible, or before the seed has had a chance to germinate, the ridges dragged off with a spike-tooth harrow. When border irrigated a field is planted flat, irrigated and thoroughly harrowed as soon as possible afterwards.

Sometime land is prepared for planting in furrows as a means for procuring a stand of plants on alkali land, also for the purpose of affording protection to young plants from high winds and shifting sand. In these cases the land is irrigated through the furrows before planting.

Variety and Seed.—It is important first to adopt a variety of cotton which can be grown at the greatest profit and second to plant pure seed.

The upland variety as well as the long staple may be produced over the entire irrigated cotton area, though varietal habits and characteristics adapt certain types to certain localities. The Pima long staple is probably the most valuable cotton that can be grown anywhere in the world; consequently where good yields can be produced at a reasonable cost it will undoubtedly prove to be the most profitable variety that can be grown. A long season is required, however, to mature a full crop of this cotton and for that reason it can be produced profitably neither in boll-weevel infested districts nor in sections having a relatively short growing season. It is particularly adapted to conditions in the semitropical valleys of Arizona and California. There are several upland varieties grown in the irrigated cotton belt, chief among them being Acala, Durango, Mebane and Lone Star. These varieties and some others are well adapted to conditions in southwestern United States and apparently there is no great difference in yield and quality of fiber that may be obtained from them. The matter of choice among them is secondary to the desirability for community production of one variety.

Cotton is a plant that readily hybridizes and deteriorates; furthermore mixing takes place at the public gin and crossing results when several varieties are grown in adjoining fields. If

this condition is not very carefully watched and steps taken to maintain pure seed, the stock will soon run out, resulting in small yields and low commercial value because of ununiformity of length and quality of fiber.

Planting.—Cotton should be planted as early as possible with a reasonable assurance of securing a good stand because a long season is required for a maximum crop and the young plants develop a more normal growth when hot weather is not encountered too soon. Early planting is more essential for long staple than for the upland varieties. The proper time to plant will also vary somewhat with the season and this variation will be more for some localities than others. In southern Arizona and Imperial Valley, California, the most desirable season is from Mar. 1 to Apr. 15; in San Joaquin Valley, California, from Apr. 1 to May 1; and in New Mexico and western Texas from Apr. 15 to May 15.

Either a one-row or a two-row planter may be used, though the latter is preferable because with it more rapid and a more uniform depth of planting is possible. Under most soil conditions it is desirable to equip planters with one of several special shoe attachments. These are used for several purposes, *i.e.*, limiting the depth of planting, especially necessary for dry planting; pushing dry soil, clods and trash aside; and providing special cultivation of the soil and covering for the seed when planted in heavy soil.

Experiments have shown that wide spacing of rows is desirable so as to permit sunlight to reach the lower branches. On rich soils the furrows should be from 3 1/2 to 4 feet apart while on lighter and poorer soils from 3 to 3 1/2 feet will be ample.

Depth of planting depends upon the type of soil and date of planting. Heavy soils should be planted shallow, and sandy soils deep. Early planting should be shallow, and late planting deep. The range of depth should be from 1 to 2 1/2 inches.

The amount of seed that should be planted will vary with the date of planting; however, heavy seeding should always be practiced to insure a good stand. For early planting from 30 to 40 pounds of seed per acre should be used, and for late planting about 25 pounds. In actual practice the rate of seeding is not always so heavy and in some instances from 12 to 15 pounds per acre is used.

THINNING.—A close study of the characteristics and habits of the cotton plant have recently brought about changes in the method of culture, particularly in regard to the time of thinning and spacing of plants in the row. The practice of very early thinning and wide spacing of former years has been generally abandoned.

Close spacing suppresses vegetative growth and makes a smaller plant which bears relatively few bolls, but the greater number of plants per acre usually results in a greater yield. For rich soils and for late planting, close spacing is particularly desirable, since the tendency to develop a large plant is greatest under these conditions. Likewise on light or poor soils close spacing in the row is very desirable, since greater yields result from that practice. Usually a 12- to 14-inch spacing is considered good practice.

Thinning before plants are 4 to 6 inches tall is not advisable, since up to this stage of growth damage to a young stand of plants is likely to occur from sand storms, hail storms, sore shin and cut worms. Later thinning, or when plants are from 10 to 12 inches high, is desirable for cotton planted in very rich soil and for some varieties for the purpose of suppressing vegetative growth.

IRRIGATION.—It is doubtful if there is another annual crop produced that is so sensitive to soil-moisture conditions; consequently irrigation as a means of controlling this factor is a distinct advantage.

Only general principles can be laid down as to the practice that should be followed in irrigating cotton, since requirements change with variations in climate, conditions of crop and type of soil.

As has already been stated, the soil should be thoroughly moistened with water to a depth of 5 or 6 feet at the time of planting. Unless plants distinctly show the need of moisture no additional water should be applied until the early fruiting stage, which usually occurs during the fore part of July. This practice during the early growth is for the purpose of developing an extensive root system and to prevent too rapid and rank a growth of plants, which characteristic, if established, may continue throughout the season at the expense of fruitfulness. The best indication to follow for need of moisture is the appear-

ance of the plant. A vigorous but slow growth should be maintained. Lack of water is indicated by the wilting of the leaves during the hot hours of the day, but ordinarily during this period it is better to delay irrigation until some of the plants show signs of wilting before noon, or do not revive from a wilted condition after four o'clock in the afternoon. If the fact has been established through previous experience with a particular type of soil that one or more additional irrigations will be required before July 1, it is preferable, when possible, to apply this water before the hot weather sets in, since there will then be less tendency to force rank growth.

After flowering begins, the water requirements change. The plant is now entering its fruiting period and must have more water, since, in addition to making a normal plant growth, it is producing fruit. A deficiency of moisture at any time during this period may result in the shedding of some of the fruit already on the plant and may stop further fruiting; consequently irrigation water should be so applied that the needs of the plant at all times will be well supplied. Through this period a slow, vigorous growth of plants should continue; very little or no wilting of the leaves should be permitted; and the flowers should be kept low down on the plant. The upper leaves of a properly watered plant will be of medium size, rather deep lobed and of a leathery texture. A dull or bluish-green colored leaf denotes need for water and is the sign followed by most cotton growers.

After the picking season starts the need for water is not so great. Water should be applied sparingly with the idea of keeping just enough moisture in the soil to mature the late crop. An excess amount of moisture in the soil during the late fall is not desirable as it undoubtedly delays opening of the bolls and may actually damage the bolls.

Cultivation.—Cultivation should start as soon as the plants are out of the ground and should continue as long as teams and implements can pass through the rows without serious damage to the crop. The first cultivation should be shallow, and is usually best accomplished by means of a spike-tooth harrow drawn diagonally across the cotton rows. A disk cultivator, or an ordinary cultivator equipped with single disks next to the cotton row, is usually very satisfactory for the second cultivation.

Later cultivations should be shallow and are best accomplished by the use of small shovels and sweeps of various sizes. The more frequently cotton is cultivated the more assurance of a good crop, but particularly is it necessary to work the soil following irrigations and rains.

The soil is gradually worked toward the cotton rows during the later cultivations in order that the cotton plant might be better supported and that a furrow might be provided through which to irrigate.

Cost of Production.—It is impossible to give in detail the cost of producing a crop of cotton which would be applicable to all conditions, since the items might vary as much or more than 100 per cent.; however, the gross possible returns obtainable from a crop of cotton governs, to a large degree, the combination of conditions that can be met in producing a profitable crop and, though single items of expense may not agree for all localities, the total cost of production must be somewhere near the same. Large growers throughout the cotton sections agree that the cost of handling an acre of cotton up to harvest time amounts to from $20 to $25. The additional expense involved in harvesting, ginning and marketing will vary with yield obtained as will also the profits that are realized.

From what is being accomplished by individual growers in all of the irrigated cotton sections it is reasonable to expect a yield of 1 1/2 bales per acre where the crop is properly taken care of, and where the soil is productive. It should be remembered that the yield will depend largely on the following:

1. Selection of good soil.
2. Thorough preparation of the land that water may be applied evenly to the soil.
3. Careful selection of seed for planting.
4. Securing and maintaining a full stand of plants.
5. Frequent shallow cultivations.
6. Infrequent early irrigations to guard against overluxuriant growth and to establish deep rooting.
7. Thorough and careful irrigation after flowering begins to insure normal growth of plants and bolls and steady setting of fruit.
8. Moderate irrigation in the fall to mature the late summer and early fall setting.

50. The Growing of Sugar Cane under Irrigation.—Sugar cane is produced in all the Gulf states from Florida westward and for a distance of more than 200 miles inland from the Gulf Though grown in a number of southern states it is only in Texas and in the island possessions of the United States that it is irrigated. This subtropical plant requires a long growing season of at least 10 months to produce a profitable crop. In the Hawaiian Islands the first crop from seed requires 18 months to mature and the subsequent or stubble crops 22 months to reach maturity. The average crop thus obtained yields about 4 1/2 tons of sugar per acre. Coming inland from the Gulf of Mexico in Texas a distance of 75 miles or more the frostless period is not sufficient in length to produce a commercial crop of sugar but over a considerable area cane is grown for the manufacture of sirup.

Irrigation.—Sugar cane, not unlike other cultivated grasses, grows most luxuriantly under humid conditions. The results of experience seem to show that the moisture content of the soil should not fall below 25 per cent. during the season. In the lower Rio Grande Valley of Texas during the season 1908-1909, 42 acres produced 44.75 tons of stripped cane per acre. The soil was a sandy loam very well drained. The crop was planted during November and December. It received during the growing season 25 inches per acre in five irrigations and 8 acre-inches which were applied before planting made 33 inches in all. The total amount received by irrigation and rainfall amounted to 55.84 inches.

In retentive soils 12 to 13 irrigations of 4 inches each are usually applied to sugar cane. Two of these are generally given prior to Feb. 1. In the 5-month period from Feb. 1 to July 1 the interval between irrigations is 20 days and from July 1 to Sept. 30 it is 30 days.

While a high moisture content in the soil increases the yield it also increases the moisture in the stock which adds to the cost of hauling and manufacture and undoubtedly decreases the percentage of sucrose. The more water in the cane the more the machinery required for reducing it and the greater the time consumed in evaporating. It is the action of the sun on the leaves that produces the sugar in the plant and when the time arrives for maturing and producing the sugar water should be withheld.

The furrow method of application is commonly used but there is a difference of opinion among growers as to the proper location of the furrow. Some advocate running the water in a furrow along the cane row, others in two shallow furrows on either side of the row while still others make use of the flat central furrow. All growers agree in running the water along the row, the first two applications after seeding. The difference of opinion as to the location of the furrows arises, perhaps, from the action of the water in different types of soil. In heavy clay soils the water reaches the roots more readily if applied around the stocks which it follows into the ground. In open porous soils this advantage is lost and water is applied more readily alongside the row. The grower should watch the movement of moisture and learn the best method to apply in his individual case.

Head ditches having a capacity of 3 to 5 second-feet are constructed across the field at intervals of 300 to 600 feet. The grades of these ditches may vary from 0 to 2 inches per 100 feet. Ordinarily heads of from 2 to 3 second-feet are used in irrigating, each head being divided between 5 to 10 furrows.

Cultivation.—To prevent weed growth as well as to check evaporation and packing of the soil, cultivation should follow the application of the water and continue until the cane is too large for such treatment. The first tool used after irrigation should be one that will pulverize the surface without turning up moist soil from below. All cultivation should be shallow as cane is a grass and a shallow-rooted feeder. Until the crop thoroughly shades the ground cultivation should be continued.

When ready for harvesting the cane is stripped, cut, topped and placed in windrows on the ground and is then transported to the mill on wagons or treadways.

The following statements are taken from W. P. Alexander's bulletin on "The Irrigation of Sugar Cane in Hawaii" published in 1923 by the Hawaiian Sugar Planters' Association. A typical irrigation layout for sugar cane in Hawaii is outlined in Fig. 104.

Improvement in the practice of irrigating sugar cane is almost certain to result in more tons of sugar per million gallons of water used, in less labor in irrigating and in correlating good practice in use of water with other factors of crop production such as fertilizing, cultivation, weed control, planting, etc.

More definite information is needed on the following: (1) How much water is needed for one irrigation to produce optimum growth? (2) What amounts are needed at different periods of growth? (3) What amounts are required by cane at different seasons of the year? (4) When should irrigation be stopped before harvesting? (5) What amounts of water do different varieties need?

Alexander has given more or less data on all these queries. He shows, for example, that the upper 6 feet of soil cannot retain

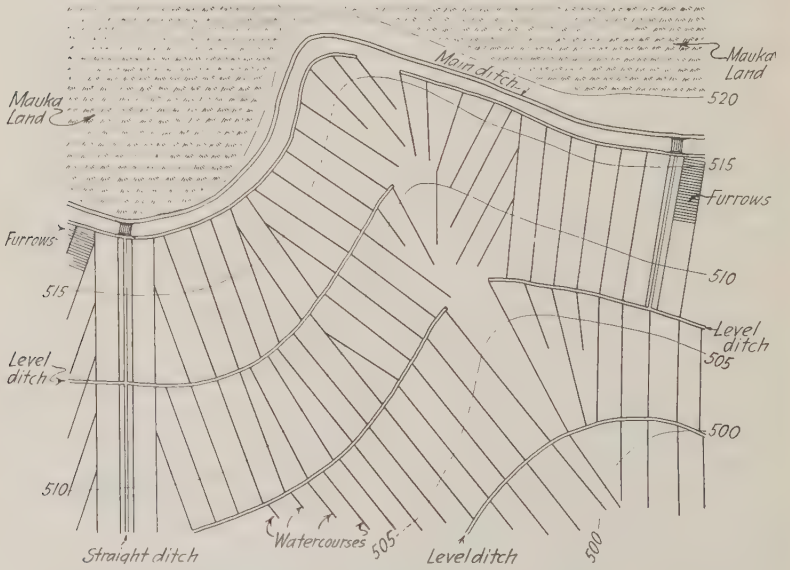


FIG. 104.—Typical layout of an Hawaiian furrow system for sugar cane.

more than about 4 1/2 acre-inches of water and that the true value of irrigation is measured not by the amount of water applied to the soil but by the amount of moisture retained by the soil within the root zone. He also shows that the growth of cane depends on temperature and that temperature in turn depends on the season. During the colder winter months there is little growth, and, consequently, the water requirement for this period is less. The relation between temperature and cane growth is shown graphically in Fig. 105.

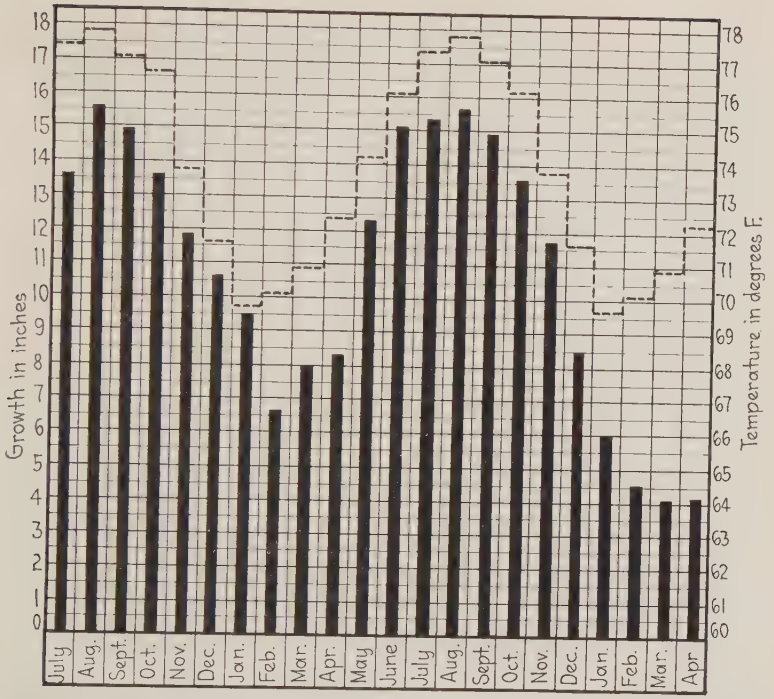

Growth in inches
Temperature in degrees F.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78
July Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr

FIG. 105.—Relation of cane growth (black bars) to temperature (dotted line).

FIG. 106.—Sugar cane in Hawaii—left, irrigated; right, non-irrigated.

It seems to the author that valuable data could be obtained by growing cane in large double-jacketed tanks, the inner tank having a double bottom, to admit of drainage. By varying the quantity of water applied to each set of tanks the relation between water applied, or the percentage of soil moisture, and the yield might be determined. In a similar manner the effect of time and frequency of irrigations might be worked out.

That sugar cane requires to be irrigated in the Hawaiian Islands is indicated by Fig. 106 which shows an irrigated crop to the left and a non-irrigated crop to the right.

51. Irrigation of Truck Crops.—Under the general supervision of the author, investigations were carried on for a number of years by Messrs. Rockwell, Kidder and Hemphill in the lower Rio Grande Valley in Texas to determine among other things the proper use of water on truck crops, and the following notes are gleaned from their reports.

Onions.—Onions are grown chiefly for home consumption in all irrigated sections. Conditions in the Southwest and more particularly in the lower Rio Grande Valley, Texas, are so favorable for the growth of onions that their production on a commercial scale has become an important industry.

Some varieties are seeded in the spring in the direct and ordinary manner. The more common practice, however, is to sow the seed in seed-beds in the fall and afterward transplant to the field. The white Bermuda is the most popular variety for fall seeding. The ground chosen for the seed-bed should not have much slope and should be thoroughly leveled and the surface pulverized. Ordinarily the beds are laid out 10 to 12 feet wide and 30 to 50 feet long by constructing a head ditch along the ends of the rows and throwing up a back furrow at right angles to the head ditch. The seed is drilled in by hand late in September or early in October on a flat surface not to exceed 1/4 inch in depth in rows 12 inches apart, about 25 pounds of seed per acre being used. An acre of seed-bed will furnish plants for 8 acres in the field. The soil is kept moist by frequent light flooding or sprinkling, the overhead spray method being well adapted to seed-bed irrigation. As soon as the plants appear cultivation with hand tools begins. By Dec. 1 to 15 the plants should be the size of lead pencils, when they are ready to transplant.

The field should be well plowed and the surface thoroughly leveled and pulverized. Ordinarily the furrow or border method of irrigation is practiced. In either case the head ditches are spaced from 35 to 200 feet apart and are given a capacity of 1 to 3 second-feet. The beds are made from 10 to 14 feet wide by turning a back furrow with a turning plow or disk.

Care should be exercised in securing good seed, and thrifty, vigorous transplants are of equal importance. The latter should be graded to secure a more uniform maturing and a better crop. They are pulled from a moist seed-bed, the roots clipped to 1.4 inches and the tops cut back, leaving a plant about 5 inches long. They are distributed along the row and set 3 or 4 inches apart and 2 1/2 inches deep, the soil being placed closely about them.

Irrigation.—Immediately following transplanting the field is irrigated by flooding between borders or along the rows. One to three irrigations may be necessary prior to February depending on the season. During the growing period water is applied every 8 to 12 days at a rate of 1 1/2 to 4 inches per application. Eight to ten irrigations are given in all, totaling 12 to 30 inches. Under economical methods of distribution and use, 18 inches will mature a crop. Heads of from 1 to 3 second-feet are used, a second-foot being divided between two beds or else between 20 to 35 rows.

Harvesting.—Upon the first sign of falling tops, irrigation should cease. When the plants are mature, indicated by the fallen tops, they are plowed out with a single-shovel plow, placed in windrows and allowed to dry. The roots and tops are then clipped and the onions placed in crates and hauled to the sorting shed. After grading they are packed in 50-pound crates and stored or placed upon the car.

Cabbage.—In the latter part of November of each year when the plants were about 2 1/2 inches high they were transplanted in rows 20 inches apart and 30 inches between rows. The results of 4 years' experimentation on from three to six plots each year on sandy loam and clay soil point to the conclusion that for that locality 18 inches of water would suffice for heavy yields and that 1 acre-inch might be applied at transplanting followed by two 2-inch irrigations 7 days apart, followed in turn by three 3-inch irrigations 15 days apart. The relation between

water applied and yield on loam soil is shown graphically in Fig. 107.

Lettuce.—Similar experiments were carried on with lettuce which was seeded in rows 18 inches apart and subsequently thinned to 8 inches in the row. In the 3-year trial the largest yield obtained was 23,237 pounds per acre, and the quantity of water recommended was about 1 acre-foot per acre applied in frequent light waterings, the maximum quantity being needed at heading time. The relation of water requirements to crop yield is shown in Fig. 107.

Cauliflowers.—The experiments for this crop were confined to one season on both sandy and clay soils. On the sandy soil

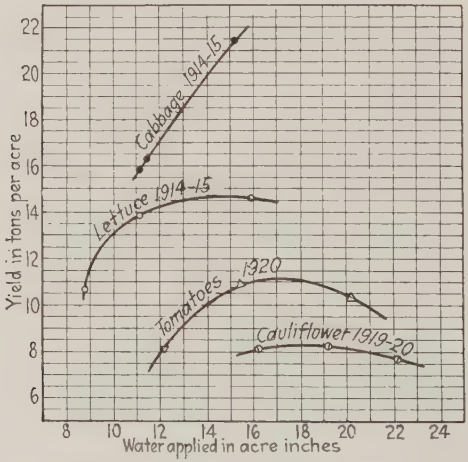


Fig. 107.—Relation of yield to amount of water applied.

with a yield of 10,000 pounds per acre, 16 inches of water including effective rainwater produced 6 per cent. more than 10 inches of water. On the clay soil with a yield of 16,000 pounds per acre 10 inches of water produced 4 per cent. more than 16 inches of water. The tentative conclusion reached was that 15 acre-inches per acre would meet the requirements of cauliflowers.

Tomatoes.—The curve in Fig. 107 shows that about 17 acre-inches per acre is a near approach to the water requirements of this crop when grown on sandy soil. The water requirement for clay soil was less but the yield was also less.

ARTICHOKES.—The growing of artichokes on a commercial scale in central California is confined for the most part to the coast extending south of San Francisco for a distance of 75 miles. The variety grown is the "green globe" derived from Italy. The normal rainfall of the locality occurs from the fall months to Apr. 1, or later, and amounts to over 20 inches. There is accordingly little need for early spring irrigation. Irrigation usually begins the first week in June and continues until the rains come with intervals of 25 to 30 days. An application of 3 acre-inches per acre at each of four irrigations is considered sufficient. The old Italian custom of spading the ground for 2 feet on each side of the row in the spring still endures and, on account of better penetration of water, more than 3 inches is applied at the first irrigation and somewhat less at subsequent waterings. The cost of irrigation water, as given by F. L. Lathrop of the Peninsula Farm Company, depends on whether the water supply is by gravity ditches or pumped from wells. The former varies from $4 to $6 per acre and the latter from $7 to $15 per acre.

52. Irrigation of Grapes.—THE NEED OF IRRIGATION.—The growing of grapes under irrigation is perhaps less usual in the western United States than their growth without irrigation. This is mainly due to the fact that in general less moisture is required for grapes than for most other fruits. A further probable reason is that the advantage to be gained by irrigating grapes on the less moist soils is not yet fully appreciated; and besides, considerable areas of grapes are grown on hillsides where water for irrigation is not available and where its distribution would be very difficult even if it were at hand.

VARIETIES USUALLY GROWN.—While grapes are found throughout the United States, their commercial production in the western United States is mainly limited to the Pacific states and they are most largely found in California. For the perfection of the grape, rather higher temperatures are required during ripening periods than obtain in the mountain areas of the interior. While the commercial grapes of the eastern and central states are varieties of native American species, the commercial grapes of California and the other Pacific slope states are varieties of the European species *Vinifera*, although several American species, as *Riparia*, and *Rupestris*, are used as grafting stock for

the *Vinifera* and other European species grown commercially in the West. Wickson lists the following as the most popular varieties among California fruit growers: Muscat, Tokay, Cornichon, Thompson, Emperor, Malaga, Rose of Peru, Zinfandel, Black Morocco, Sweet Water, Verdal, Carignane, Black Prince, Alicante, and Sultana.

When and How to Irrigate.—There is no well-established practice in either the time or the manner of irrigating grapes. In the Fresno section of California, which is the raisin-grape center of the United States, where the ground water is in most cases relatively high, it is customary to irrigate only during the first 2 years of growth, the vines receiving ample moisture after that from below. In such cases the usual practice is to apply water twice during the season, with a total seasonal application of about 1 acre-foot. Some growers, however, prefer to apply the same amount in four irrigations instead of two. On the higher ground about Fresno, vineyardists usually apply water on old vineyards at least once each season. In the vineyard sections of Sacramento and San Joaquin counties, California, some growers irrigate more frequently, watering every 7 to 14 days, with as many as 14 or 15 in a season not being uncommon. Many of the vineyardists in these counties, however, do not irrigate at all. In the Napa and Sonoma County grape sections of California, where the annual rainfall averages from 25 to over 40 inches, vineyards are not irrigated nor are southern California vineyards usually irrigated, except in the desert sections, as about Coachella where they receive three or four waterings annually. While, as indicated, practice varies widely, the general principle to bear in mind is that, whether they receive it from rainfall or by irrigation, vineyards should have ample moisture prior to and at the time of budding in the spring, with a diminishing amount as the season advances. The quantity to apply is dependent entirely on the retentiveness of the soil and on the amount lost by evaporation, from 15 to 20 acre-inches per year probably being the minimum quantity it is desirable to apply in addition to rainfall. Care must be taken not to irrigate late enough in the season to stimulate growth of the vines beyond ripening of the fruit. Bioletti holds that with deep soils very retentive of moisture best results are obtained by withholding all irrigation after April, the mois-

ture then in the ground to be conserved by cultivation. In shallower or less retentive soils he holds that an irrigation just after the fruit is set and another a little before it reaches full size are advisable. In any case, too frequent irrigations should be avoided with grapes as with other deciduous fruits.

The usual method of irrigating vineyards is by means of furrows. About Fresno, Calif., two furrows are run in each "land" 12 to 24 inches from the vines, small checks being placed across the furrows every four or five rows to hold the water. In the best practice the water is confined to the furrows, the more crude practice practically resulting in the basin method sometimes used in orchards. Frank Adams states:

> One of the best systems of vineyard irrigation observed in California was seen at Elk Grove, Sacramento County. There furrows about 12 inches deep are plowed in every other "land" by means of a five-horse home-made sulky lister plow with enlarged mouldboards, the furrows later being enlarged to a bottom width of about 6 inches and "packed" with a home-made "logger" constructed like an ordinary crowder and shod with steel plates. By this method of furrowing shallow wetting and consequently shallow rooting of the vines are prevented.

53. Irrigation of Small Fruit.[1]—The berry patch is almost as common and almost as indispensable on irrigated farms as the family garden. The area devoted to the commercial growing of small fruit under irrigation is, however, comparatively small and is of necessity limited to sections having easy access to large markets.

The crops discussed in this article include strawberries, raspberries, blackberries, loganberries, and dewberries. The methods of cultivation and irrigation of these crops vary only slightly in the different irrigated sections.

Preparation of Land.—Where small fruits are grown under irrigation in a level country it is necessary that the land be carefully prepared before planting. This applies particularly to strawberry fields, because the streams of water used are quite small and unless the land has an even slope, water will collect in depressions and menace the berry vines. Plowing and harrowing are indispensable in securing a good bed for planting, and

[1] For further information on this subject see *Circ.* 154, *Univ. of Calif.*, by Wells A. Hutchins.

further are often necessary to loosen the soil where leveling is done. In some sections the practice is to plow twice before grading; once to a depth of 8 to 12 inches and again to a shallower depth. Leveling the land for a berry field is very particular work and is usually done by special grading implements, often home made. The system for distributing water may consist of earthen ditches, wooden flumes, or pipes. In California, small wooden flumes are most widely used. Earth ditches cost less to make, but require more labor in irrigating because of the necessity for opening and closing many furrows at each irrigation, and of course allow seepage losses. Furrows may be made with a shovel, throwing alternate shovelsful of dirt to the right and left to equalize the furrows and ridges, or may be made with horse-drawn implements, such as V-scrapers or V-shaped cultivators or a one-horse plow; the furrows having previously been marked out with strings or with a wheelbarrow or sled.

Where leveling is done and the land is carefully leveled and prepared, the cost of preparation will be about as follows:

	Per Acre
Surveying	$2.00 to $2.50
Plowing and cultivating before planting	5.00 to 10.00
Grading	3.00 to 40.00
Head ditches and flumes:	
If made of earth	2.00 to 4.00
If made of lumber, 8-inch, V-type	28.00
If made of lumber, 12-inch, V-type	30.00
If made of lumber, 8-inch, rectangular type	30.00
Making the furrows	2.00 to 7.00
Total	$14.00 to $89.50

It should be noted, however, that the maximum is rarely expended for preparing land for small fruits, unless the land is to be put into some permanent irrigated crop justifying a large expenditure. In many locations the surveying and grading may be eliminated.

Strawberries.—Strawberries are the most important berry crop grown commercially in the West. They can be grown on a variety of soils but thrive best on a sandy loam. The lighter soils produce earlier berries but the heavier soils often give larger yields and for a longer period. One of the chief essentials

is that the soil be well drained and for this reason a porous subsoil is desirable.

The soil should contain a good supply of moisture at the time the plants are set out. In setting plants a spade, dibble or trowel may be used to make the hole, the plant inserted after the roots have been cut to a length of about 3 inches, and the earth pressed firmly around the plant with the hands. It is a good plan to carry the plants in a vessel containing water until they are ready to set in the ground. There are two general methods of planting, known as the hill system and the matted-row system. The former system consists of growing the plants singly in rows, for which purpose all runners are cut off, while the matted-row system involves the filling of intermediate spaces in a row by runners from the mother plants. There are many modifications of these methods. In Oregon, if plants are to be cultivated both ways, they are usually set 2 1/2 by 2 1/2 feet apart or 3 by 3 feet apart. If not intended to be cultivated both ways they are set 4 1/2 by 3 feet apart. In Colorado if the hill system is used the rows are 2 1/2 to 3 feet apart and the plants 12 inches apart in the rows; while if the matted-row system is employed the plants are set 18 to 24 inches apart and the rows are spaced 3 1/2 to 4 feet apart. The hill system is rarely used in California, most strawberries being grown on continuous raised beds and a few on level beds. The classification in that state consists of the single-row system, in which the rows are 22 to 34 inches apart and the plants 6 inches to 4 feet apart in the rows, depending upon their being used as "singles" or as parent plants; the matted-row system, consisting of raised beds 32 inches wide and furrows 22 inches wide and 3 to 6 inches deep, the plants being set out in double rows on each bed, the rows being 20 inches apart and the plants 10 to 22 inches apart in the row, depending upon the variety of plant, the runners eventually making one complete matted row, there being variations from these dimensions in some sections of that state; and the double matted-row system, the features of which are that furrows are 6 feet apart from center to center and 12 inches deep, and on the raised bed between two furrows the plants are originally set out in double rows some 3 1/2 feet apart and 1 foot apart in the row, runners from each plant being made to take root in order that when the

two parallel rows on a raised bed have completely formed there shall be an intermediate bare space 18 inches wide for cultivating and for providing a dry path for pickers. The ordinary matted-row system is most extensively used in California. By the hill system larger berries are produced, but the yield is larger and the fruiting period longer when the matted-row system is followed. Plants may be set out either in the spring or the fall, but if the winters are at all severe spring planting is preferable.

It is of vital importance that strawberries have an ample supply of moisture at all times, especially during the fruiting stage. Few plants are quicker to feel the effect of a deficiency of moisture than strawberries. The root system is usually confined to the first 12 or 14 inches in depth and seldom extends below 18 inches, so that the upper 2 feet of soil must be kept moist with frequent light applications of water. Local soil and climatic conditions must govern the amount and frequency of irrigation but the condition of the soil and plants should be carefully observed and water should be applied before the plants begin to suffer. After the vines cease to bear one or two irrigations usually suffice.

The practice in Pajaro Valley, California, where many summer days are foggy, is to irrigate immediately after picking, which means every 10 days or 2 weeks in early spring and in the fall, and every week at least during the summer. In other parts of the state the irrigations may be as often as every 4 or 5 days in hot weather and even more frequently for light soils, and about every 2 weeks for heavy soils.

In Colorado, the best practice consists in making shallow furrows close to each row of plants as soon as they are set out and in applying water immediately even if the ground is moist. This settles the earth around the plants, is an insurance against possible dryness and gives the plants a vigorous start.

In order properly to regulate the amount of water in each furrow where earth ditches are used, it is best to take the water from the supply ditch through metal tubes or lath boxes rather than to make cuts in the ditch bank.

Some growers prefer to irrigate in every alternate row while the dry rows are being picked. This makes it possible for irrigation and picking to proceed at the same time. It is important

that the berries be picked frequently, every day if possible, as it is detrimental to the vines to allow fruit to decay on them.

The profitable life of strawberry vines is 2 to 5 years. Most growers claim they are not profitable after the third year. Strawberries should be cultivated or hoed frequently throughout the growing season in order to keep down the weeds and aerate the soil.

Among the popular varieties of strawberries grown in the West may be mentioned the Brandywine and the Klondike.

Raspberries.—Raspberries are of two general kinds, red raspberries and black raspberries or black caps. Like strawberries and other small fruits they require a well-drained soil. In the Pacific coast states they are planted either in hills 6 to 8 feet apart each way or in continuous rows 5 to 8 feet apart and 3 to 5 feet apart in the rows. In the Rocky Mountain states if winter protection is necessary the rows are spaced about 7 feet apart and plants 2 to 3 feet apart in the rows. When winter protection is not necessary the rows are 5 to 6 feet apart and the plants 3 to 5 feet apart in the rows.

In sections where the winter temperature is likely to remain at zero or lower for any length of time it is necessary to cover the plants to protect them from winterkilling. This is accomplished by removing the earth from one side of the row and bending the canes over to the ground, then partially covering with coarse manure or earth.

In California, the planting season extends from November to February while in the mountain states plants may be set out either in the spring or fall, spring planting being preferred if the winters are severe.

Raspberries require a moderate amount of water, and as a rule feel the effect of drought more quickly than blackberries. The aim should be to keep the surface soil in a fairly moist condition throughout the growing season. Water is applied in shallow furrows as near to the rows as possible without danger of injury to the plants in cultivating, although in some sections one furrow is located squarely between rows. Irrigations should occur at intervals of 10 days to 3 weeks. In some soils even more frequent irrigation is necessary. In most parts of California several irrigations follow the fruiting season. Each irrigation should be

followed by a shallow culivation. Deep cultivation during the growing season is never advisable for bush berries of any kind, since it disturbs the delicate feed roots near the surface. The practice in some parts of California is to irrigate with two furrows between plant rows and with an extra ridge separating the furrows between plant rows to provide a dry path for pickers.

It is good practice to prune all old canes just after the fruiting season and later cut the main canes from 3 1/2 to 4 feet in length and remove all small, inferior growth. Where there is danger of winterkilling it is best not to remove the old canes until spring.

A common method of trellising the vines is to sink a line of posts 4 or 5 feet high and 10 to 30 feet apart in the row, to which an 18-inch cross-arm is nailed 3 feet from the ground. To the ends of these arms heavy wires are stapled to form lateral supports for the canes. Many growers, however, do not consider it necessary to provide supports of this kind, while still others provide even bush berries of the upright type with some form of support because of the weight of the canes when loaded with fruit.

The Cuthbert is one of the most common of red raspberries and the Gregg is prominent among the black caps.

Blackberries.—What has been said regarding raspberries applies, in large measure, as well to blackberries, since the habits and requirements of these berries are very similar. The blackberry is hardier than most other bush berries and will not suffer as quickly from drought, but an ample supply of moisture nevertheless is necessary for an abundant yield of large, luscious berries. Under similar conditions they are irrigated less frequently than raspberries.

Dewberries.—These berries, distinguished from blackberries chiefly by their low, trailing habit and by their generally shallower root systems, are more dependent upon irrigation than are many varieties of blackberries and are irrigated somewhat more frequently than blackberries under the same conditions, particularly on light soils. They are planted shallower than blackberries and are probably best irrigated by means of furrows midway between the rows rather than close to them. Having the vines high enough to keep them out of the water when irrigating has been found to be the safer practice. The fruiting

season of the dewberry is earlier than that of the blackberry and for that reason renders it more dependent on early waterings.

Loganberries.—This berry is a California hybrid of the wild blackberry and the red raspberry. Its treatment should be similar to that required for the raspberry except that it is less adapted to successful growing without irrigation and is usually spaced wider apart in the rows.

Currants and Gooseberries.—These are more limited in their area of successful growth than are any of the bush fruits previously metioned. In California currants are usually grown commercially without irrigation within the cooling influences of the coast. Gooseberries grown in the warmer San Joaquin Valley are irrigated every 10 days in the spring and until the crop has been removed, then about every 2 weeks through the summer and less frequently in the fall. Deeper cultivation is possible after irrigation than is the case with other berries.

54. Supplemental Irrigation in Humid Regions.—It has long been recognized that the artificial watering of crops in humid regions during drought periods results in increased yields. However, the cost of installing an irrigation system, coupled with the uncertainty as to how frequently it will be needed, has prevented anything like a general adoption of irrigation in such areas. Irrigation along the Atlantic seaboard differs in some important particulars from that of the arid region. While the greater part of the arid region is irrigated from ditches and canals serving two or more farms, in the humid region practically all irrigation is of single farms and as a rule the equipment includes a pumping plant.

The crops most commonly irrigated are truck, orchard and small fruit. Only under exceptional conditions is it economically feasible to irrigate ordinary field crops, such as meadows, corn and wheat. The gain in the net returns under irrigation must be enough more than that when rainfall alone is depended on, to pay interest and depreciation on the irrigation plant. Such a plant will cost from $150 to $400 per acre, depending on the method of irrigation followed, the accessibility of a water supply, the area irrigated, etc.

Three methods of applying water are followed, *viz.*, surface, subsurface and spray irrigation. The two last-named methods

have been already described (Arts. 26 and 39). On probably 90 per cent. of the area irrigated in the region east of the Mississippi River, one or the other of these two methods is followed. In case the surface method is used the water is applied to the crops through furrows in a manner somewhat similar to furrow irrigation in arid regions. The chief difference consists in the manner in which water is carried to the field and admitted to the furrows. Owing to the irregular topography usually found in the eastern states, it is seldom feasible to conduct water in open ditches. Instead it is carried in pipes laid underground and brought to the surface in upright or riser pipes in which is a valve by which the flow is controlled. These are placed at intervals of 30 to 100 feet and each is made to serve a number of furrows. If slip-joint pipe is used to conduct the water away from the risers, a special portable hood is clamped to the valve casting. It has a sheet-iron elbow which may be pointed in any direction.[1]

The frequency of droughts is of great importance when attempting to arrive at a decision as to whether an irrigation plant will justify the expense. In this connection the following table, taken from the "Yearbook" of the Department of Agriculture for 1911, will serve as a guide in preparing similar data for any locality where rainfall records covering 10 or more years are available.

AVERAGE ANNUAL RAINFALL, NUMBER OF DROUGHTS, AND NUMBER OF DAYS WHEN IRRIGATION WAS REQUIRED AT REPRESENTATIVE POINTS IN THE HUMID REGION DURING TEN GROWING SEASONS

Station	Average annual rainfall, inches	Number of 15-day periods or over with less than 1 inch of rain	Number of days when irrigation was required
Ames, Iowa	30.39	23	190
Oshkosh, Wis	29.78	27	292
Vineland, N. J	47.47	46	352
Columbia, S. C	47.55	62	568
Selma, Ala	50.75	60	724

The investigations conducted by Milo B. Williams for the Office of Experiment Stations have demonstrated that the economic

[1] *Farmers' Bull.* 899 (revised).

advantages of irrigation in the Atlantic Coast states should not be measured wholly by increased yields or a better quality of products. Under intensive farming where large sums are expended for fertilizers, waiting on rain before sowing the seed or cultivating the soil may prove very costly. The farmer who can moisten the soil by artificial means and plant a crop gains the advantage of having highly fertilized soil utilized without delay from dry weather. The time thus saved often makes possible the growing of an additional crop on the same ground in one season at the same cost for fertilizer and at a reduced cost for labor. By properly controlling soil moisture, weeding and cultivating can be done in the best manner at the least expense and a crop of maximum yield can be produced in the shortest time and with the least risk from disease, frost, or other unfavorable conditions.

One of the greatest advantages of supplemental irrigation lies in the fact that irrigated crops can usually be marketed ahead of non-irrigated crops. Crops cannot well be planted during droughts and if planted their growth is checked. By applying water when needed at critical stages of growth the irrigator loses no time and produces a heavy crop of good quality which he markets before the bulk of like crops in his district are mature.

55. Dry-farming in Its Relation to Supplemental Irrigation.— Dry-farming is the growing of unirrigated crops by special methods of tillage and cropping in regions where the average seasonal rainfall is not sufficient for profitable farming if ordinary methods are employed. In such regions it is necessary, in the case of row crops, to maintain a surface mulch by frequent cultivation which will prevent, to a large degree, the escape of moisture by surface evaporation, and in the case of small grain, hay, or forage crops it is found that thin seeding is advisable since a few strong plants will produce a larger yield of a marketable product than a thick stand which is starved for lack of moisture. Another common practice in dry-farming regions is known as summer fallowing, which consists of allowing the land to lie idle every other year and, by keeping it free from weeds and maintaining a surface mulch, water is stored in the soil for the crop planted the following year. The employment of special methods to pack or firm the soil after plowing, the growing of drought-resistant crops, and a rotation of crops, which includes a leguminous crop to maintain

the fertility of the soil and increase its water-holding capacity, are other important aids to successful dry-farming.

The extent of land which is adapted to dry-farming is not very definitely known. Between the line of 20-inch rainfall and the margin of the arable lands along the main range of the Rocky Mountains, there is an area of over 250,000,000 acres, the greater part of which will have to be farmed, if at all, by dry-farming methods. In addition to this Great Plains area, there are large areas of dry-farming lands on the Pacific slope of the Rockies. California, for example, contains over 10,000,000 acres of arable land which cannot be irrigated on account of the lack of available water. If one assumes that the water supply of the seventeen western states will be wholly utilized when 57,000,000 acres are irrigated, there will remain over 300,000,000 acres of arable land to be dry-farmed or else pastured.

56. Sewage Irrigation.—Sewage irrigation is employed for two principal reasons: first, to provide means for disposing of the sewage from a city in a manner which will maintain sanitary conditions and protect public health; second, to utilize the water and fertilizer elements of the sewage in growing crops, the proceeds from which help to lessen the cost of the sewage disposal.

The science of sewage purification has advanced sufficiently so that at this time it is principally a matter of expense and management to reduce sewage to an inoffensive and harmless state. According to George W. Rafter, in *U. S. Water Supply Paper* 3, "the sewage from the average American town contains something like 998 parts of water, 1 part of mineral matter and 1 part of organic matter." The water comes from laundries, baths, kitchen sinks and household waterclosets. Large quantities of water are also added directly in flushing the sewer-pipe lines to keep them clean and open. Many sewer systems collect seepage water from the earth by infiltration through poorly made joints and sewer walls. Likewise, the amount of water may be reduced through leaky pipe lines, thereby affecting the character of the sewage in a reverse manner. Manufacturing communities are apt to turn oils, acids and other factory wastes into the sewers which may require special treatment or be excluded entirely before the sewage can be used for irrigation. *Combined systems*, in which both storm waters and domestic sewage are collected,

are not as desirable as *separate systems*, in which the domestic sewage is separately conducted to a disposal plant for irrigation use. Separate domestic sewage is more uniform in flow and character and better for irrigation purposes than when storm waters are added which increase the volume in rainy periods, when most difficult to utilize on the land.

Under certain circumstances, it is possible to use sewage on farm lands with practically no preliminary treatment. Examples of raw sewage irrigation are found in the cases of Redlands and Santa Ana, Calif. The population of Redlands is estimated to be 12,000. The sewage is sometimes passed through a small settling tank for the purpose of removing sand and coffee grounds which cause trouble by filling the farm pipe lines. This tank is supposed to be flushed out every 10 days in order to prevent septic action and the forming of a scum mat. The sewage is conducted through the farm lands in underground sewer pipe and delivered to the fields through a modern hydrant system. The soil is a light sandy loam, naturally well drained, but not extremely absorbent. The principal crop irrigated is orange trees which receive from 3 to 6 inches of sewage at intervals of 30 days, with the exception of the dormant season when the sewage is used on barley and oat land for its fertilizing value. Furrow irrigation is the only system of application used on all crops and cultivation follows as closely as possible after irrigation. There is no sentiment among the inhabitants against the use of sewage in this way. The success of the Redlands disposal is principally due to the efficient system of distribution, the farm management of the sewage used, the very favorable natural conditions and sufficient land.

The city of Santa Ana has an estimated population of 13,000. The raw sewage is distributed through a system of concrete pipe lines and valves to lands upon which sugar beets are grown. The soils vary from a heavy loam to a very light sandy loam. Two irrigations are used during the growth of a crop on the heavy lands, while as high as six are applied on the sandy lands during growth. The Southern California Sugar Beet Company has done considerable building up of sterile sandy lands with Santa Ana sewage by applications of approximately 8 inches every 30 days for 2 years before planting to sugar beets. The fertility

is then maintained by sewage irrigation. This company estimates sewage irrigation increases the yield of beets 3 to 4 tons per acre over clear-water irrigation.

The principal object in treating sewage which is to be used for farm irrigation is to remove the solids which tend to obstruct the free distribution and collect in the fields where they may become offensive and dangerous to health. Raw-sewage irrigation should be used only in exceptional cases where large areas of absorbent land are available and cultivation can follow irrigation closely at all times. The majority of cities are using some type of settling or clarifying tank, while in extreme cases, where the irrigation must be confined to a limited area surrounded by a closely populated section, it may be advisable to prepare for completely purifying a part or all of the sewage so that it can be discharged into natural drains during excessive rainy or freezing periods.

The commonly used septic tank, when well designed and operated, will break down a large percentage of the solids by bacterial action. The products are then discharged in the form of solution or finely suspended substances and gases. Some residue, called sludge, is left in the bottom of the tank, which can be removed at intervals and used on the land as a fertilizer of considerable value. The effluent from a septic tank is not stable nor purified from bacteria dangerous to health, and may give off more offensive odors than fresh, raw sewage before septic action has started. However, the tank effluent is in a liquid state which can be as easily applied to land as stream or well water, yet retains the most of its fertility in better form for distribution and plant food. The sewage farm should be considered as a large receiving bed and a part of the purification system upon portions of which the sewage is intermittently spread and where purifying takes place through the action of the soil bacteria and sunlight. For this reason an efficient distribution system on the farm is as important as any part of the plant. Every small stream of sewage should be under absolute control and a rotation of irrigation followed which will not overload any portion of the land and hinder the purification processes or the growth of crops. The bacteria dangerous to health may be destroyed by chemical treatment of the effluent from septic tanks, but this should not be necessary if

proper precaution is taken to prevent the sewage getting into drinking water or coming into contact with vegetables which are to be eaten without cooking. Chemical treatment is given the effluent of septic tanks of some of the newer California state institutions before the sewage is used for irrigation purposes.

One of the chief causes of failure in sewage irrigation in the United States is the lack of proper irrigation construction and management on the farm. Open ditches still, unfortunately, prevail on sewage farms. These ditches are the greatest source of offensive odors due to the dangerous accumulations of putrefying matters which collect wherever there are weeds, pockets or dead ends. Seepage from earthen ditches is apt to be large in porous soils and is dangerous to the public health. The continuous control of sewage in ditches and an efficient division into irrigation units can best be obtained with a pipe and hydrant system.

The first pipe-and-hydrant system for sewage irrigation in this country was probably installed for the city of Pullman, Ill., in 1881 and the efficiency of such construction was here well demonstrated. This system consists of either concrete or vitrified sewer pipe laid with tight joints, below cultivation and frost, in which the sewage can be carried under a light pressure head sufficient to force the sewage out of hydrants onto the surface for distribution. The pipe-line construction does not differ from that used for common irrigation water, with the exception that velocities should be kept sufficiently high to prevent deposits; also flushing facilities should be provided. Either the two-way type of hydrant valve, as used for eastern irrigation, or the southern California type, can be used successfully, each having advantages for special conditions. The pipe lines should be carefully located by an irrigation engineer and the capacities of the hydrants regulated to prevent overdosing of irrigation units. In many cases it is advisable to reserve a lower portion of the farm for taking the unpurified water from a "pick-up" system of drains which will catch any emergency runoff from the higher lands. This is especially well adapted to humid regions where heavy rains are apt to occur in the cropping season.

The management of the sewage-irrigated farm is a vital and serious problem upon which the success of the project depends. Disposal of sewage upon both private lands and municipally

owned lands is practised in the United States. The cities of Redlands, San Bernardino, and Orange, Calif., are examples of disposal upon privately owned lands. In these cases, long-term contracts are entered into with farmers who agree under bond to receive and care for all the sewage, relieving the city from all liability and responsibility if the sewage is not properly cared for. The cities cited receive some payment for the sewage, the amount varying according to local conditions. Under more adverse conditions it would be necessary for the city to pay the farmers for disposing of the sewage. The plan of selling the sewage to pay for its disposal upon private lands has the advantage of giving a greater continuity to the management of the farms than would be likely if that management were left subject to change with each change in local government, while there is a disadvantage in the city being dependent upon a farmer who may not have the ability or willingness to stay by his contract after the city has gone to the expense of delivering the sewage.

The cities of Pasadena and Pomona, Calif. are examples of municipally owned farms for sewage disposal where the municipality retains control by managing and operating the sewage farms. In many respects this practice is preferable to leasing the land to farmers for a cash rental on condition that they dispose of the sewage. Such farms should be considered as a necessary part of sewage-disposal plants. The services of the irrigation engineer and agriculturist are as necessary as those of the chemist and biologist in designing and constructing such systems of disposal, and their management should be carried on with the same degree of skill and efficiency as are used on other public utilities.

The Pasadena sewage farm of 500 acres has been in operation since 1893 and may be regarded as one of the most sucessful in the United States.[1]

The raw sewage is first passed through tanks of the Imhoff and Cameron types and afterwards conveyed in pipes and distributed over the sewage farm for the irrigation of walnut and orange groves as well as alfalfa and corn.

[1] Statement of Milo B. Williams investigating sewage irrigation in the United States for the Bureau of Public Roads, U. S. Dept. of Agr.

Largely as a result of the success of the present farm, it is now proposed to purchase a new and larger farm for the needs of the three cities of Pasadena, South Pasadena and Alhambra. The plans as formulated by R. V. Orbison, city engineer of Pasadena, and his associates call for the sewage-irrigation plant of sufficient capacity to take care of the sewage of an ultimate population of 300,000 people.

CHAPTER VII

USE OF WATER IN FOREIGN COUNTRIES

57. Irrigation in Italy.—The land area of Italy is about the same as that of Nevada and somewhat less than three-fourths that of California. Its 71,000,000 acres comprise about 20,000,000 acres of cultivated land, 16,000,000 acres of grazing land, 21,000,000 acres of forests and 14,000,000 acres of waste land. Of the cultivated land, about 3,900,000 acres were irrigated in 1924 or about 65 per cent. of the area irrigated in California in the same year. As regards rainfall, summer droughts, water supply and crops, Italy resembles California. In the valley of the Po in northern Italy the normal rainfall is 36 inches. In Apulia and Calabria in southeastern Italy it is about 20 inches, and in Sicily about 15 inches. Practically no rain falls from May 1 to Oct. 1 of each year. Water is plentiful and cheap in the north and scarce and dear in the south; hence the cheaper products, such as rice and fodders, are raised in the north, while citrus fruits are confined to the south.

Sources of Water Supply.—Water for irrigation is derived from rivers, storage reservoirs, infiltration tunnels and wells. One of the largest irrigation canals of Italy and of the world is the Cavour canal, which diverts water from the River Po to irrigate the Piedmont district. The Cavour canal was begun in 1855 by a private company which failed. The project was then bought over and completed in 1866 by the state at a cost of $20,000,000. The canal has a capacity of 3,850 second-feet of water, which is conveyed and distributed through 1,000 miles of main and secondary canals and distributaries. Its waters have transformed 250,000 acres of stunted timber and bushes of low-producing value into the most fertile rice and meadow lands of Italy, which rent for $40 to $60 per acre. Other large canals with their respective capacities which have been built during the past 50 years are the Villoresi, 1,450 second-feet; the

Marzona, 1,050 second-feet; the Tagliamento, 617 second-feet; and the Veronese, 525 second-feet. In central Italy, near Grosseto, a still larger canal, called the Ombrone, has recently been completed. It has a capacity of 21,000 second-feet and ultimately will be used for both navigation and irrigation. Its first use will be to convey the muddy waters of the River Ombrong in flood time to silt up and in this manner reclaim low-lying marshes.

Those named represent some of the largest as well as the most modern canals of Italy. There are, of course, hundreds of other canals ranging in capacity from 100 to 2,000 second-feet which were built in the long interval between the twelfth and the nineteenth centuries.

The storage of water for irrigation purposes is effected for the most part by small earthen reservoirs (*serbatoi a corona*) or else by large, loose rock or masonry dams. The first type is formed by surrounding a natural depression of 10 or more acres of retentive material with earthen dykes 12 to 16 feet high. In the second type the water is as a rule first used for hydroelectric power and afterward for irrigation. One of the largest enterprises of this kind yet attempted is now being constructed on the River Tirso in Sardinia. The dam is 195 feet high and will impound 285,000 acre-feet of water at a cost of $5,000,000. The state contributes $600,000 of the first cost and $30,000 a year for 50 years on condition that the price of the irrigation water to the farmers will not exceed $1.63 per acre-foot. At the end of 60 years the entire plant becomes the property of the state.

The infiltration tunnels to be found near Rome and Naples are narrow, unlined tunnels extending into the lava rock through which the rain water percolates and is drawn off for irrigation purposes. In southern Italy the tunnels are frequently lined with porous masonry except for the concrete base and arch rings. A common feature of all such tunnels is the use of shafts for ventilation and to facilitate repairs.

The most common methods of raising water from wells are by means of centrifugal pumps operated by fuel oils or electric motors, the water bucket (*cicogna*), which is similar to the Egyptian *shadouf*, and the chain and bucket lift (*noria*) driven by animal power.

Duty of Water.—Compared with other irrigated countries, the annual duty of water per acre is low in Italy. This is due in part at least to the large quantities of water required for rice irrigation and the watering of *marcite* or winter meadows throughout the year. In northern Italy 1 second-foot of water is used on 20 to 40 acres of rice, 40 to 80 acres of fodder crops and 80 to 100 acres of other staple crops. The specially prepared lands, called "marcite," which are seeded to mixed clovers, alfalfa and grasses to provide feed for dairy cows, require the largest quantities of water. In southern Italy where water is less abundant and where more grain is raised, the duty is higher. It is seldom, however, that water is used as economically in southern Italy as it is in southern California. According to Professor Luiggi, the cultivation of Indian corn, potatoes, tomatoes and the usual vegetables requires from 7,000 to 8,000 cubic meters of water per hectare or an equivalent of 5.6 to 6.4 acre-feet per acre. The royal commission in its report for 1913 recommended that for all new lands to be irrigated by the works proposed, 1/2 liter per second for 7 months or 2.95 acre-feet per acre, be adopted as the average duty. These new works for the Apulian peninsula alone are intended to provide water for 395,000 acres.

Cost of Water.—Luiggi[1] states that water from the state canals is sold generally at 25 francs per liter-second per annum, and that 1 liter-second is the average duty for 1 hectare of land in northern Italy. This would be equivalent to about 20 cents per acre-foot or $2 per acre per annum since the gross duty per annum is 10 acre-feet per acre. Since water is seldom used for more than half the year, the actual quantity applied to the land would be proportionally reduced. The cost of water from the Villoresi, Marzano and other canals belonging to private corporations is about double that quoted above.

As has been stated, the water from the large storage reservoirs is, as a rule, first used for power and afterward for irrigation. This double use lowers the rates to irrigators who pay from $1.63 to $3.25 per acre-foot. The water stored in the smaller reservoirs or tanks usually costs the farmers from $3.25 to $4.87 per acre-foot. Water raised by *norias* 15 to 40 feet high costs from

[1] Luiggi, Prof. Luigi, "Italian Irrigation," Rome, Italy.

$15 to $30 per acre-foot while water for citrus orchards in the vicinity of Messina costs from $45 to $72 per acre-foot.

PREPARING LAND FOR IRRIGATION.—In many irrigated districts of northern Italy the number of persons per square mile exceeds 500. This density of population coupled with low wages is in the main responsible for the adoption of methods of preparing land and applying water differing from those which prevail in western America. Nowhere is this difference so clearly brought out as in the winter meadows of Lombardy. These consist of mixed grasses and legumes sown in fields 2 to 8 acres in extent and

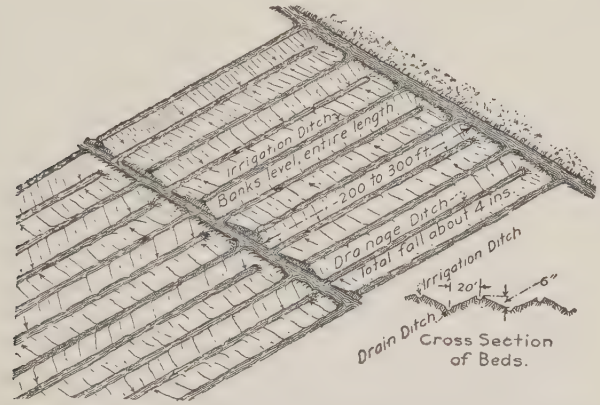


FIG. 108.—Showing method of preparing land for marcite meadows, Northern Italy.

irrigated periodically in warm weather and continuously in cold weather. The care and skill exercised in preparing and maintaining the surface of these fields, the large amount of both water and fertilizers applied, and the large profits derived from the green cow feed grown, all tend to give prominence to this particular feature of Italian irrigation. "*Chi ha prato, ha tutto*" (he who has a meadow has everything) is a Lombard adage. The average annual yield of green forage is equivalent to a crop of over 5 tons per acre of cured hay. A winter meadow or *marcite* has its surface artificially laid out in the form of flat-gable roofs (Fig. 108). Each bed corresponds to the side of a sloping roof from the ridge of which water is distributed and from the eaves of

which water is drained. Each bed varies in width from 15 to 25 feet and in length from 200 to 300 feet or more depending on the slope. The beds run longitudinally with the slope of the field and each tier from the top to the bottom is 3 to 6 inches lower than the one above. This drop enables the drainage water from one tier to flow into the feed ditches of the one next lower. In summer, canal water may be used but in winter only warm water from springs (*fontanili*) can be used on account of the danger of forming ice and killing the grass. For 5 months of winter a thin sheet of water having a temperature of 48 to 63°F. is run over the sloping beds and collected by the drains. Such beds are also heavily fertilized twice a year by means of manure, compost, and phosphates. The compost heaps occupy the corners of the fields and are made up of alternate layers of manure and a mixture of stubble, sod and silt, the latter taken from the ditches and drains. These heaps remain for 5 to 6 months, in which time they are turned over at least twice. When it is considered that all manure and compost are carried by hand in baskets and that the grass is cut and raked by hand and removed from the field in baskets, the contrast between Italian and American methods is readily seen.

The modern methods of agriculture as practised in the valley of the Po do not differ from those described by Pliny, Varro, Columello and other writers of the Roman period. Pliny describes the short scythe corresponding to our reaping hook and also the "Gallic" because introduced from Gaul which was the forerunner of our scythe and snath and consisted of a long handle on a longer and larger blade. When cut the hay was raked into windrows (*in strigam*) and then gathered into cocks (*metos*) and when dry put up into 4-pound armfuls (*manipulos*).

The grass meadows of northern Italy are either permanent or alternative. The winter meadows just described belong to the permanent class as do the summer meadows. The latter are irrigated only in summer during intervals of 7, 14 or 20 days according to the character and moisture conditions of the soil. On account of the smaller yields and the absence of freezing weather while irrigation is in progress, the summer meadows are not laid off with the same care as those of the *marcite*. The field is divided, says Bachmann, into flat, slightly inclined beds;

the water is admitted from the supply ditch into the furrows which divide the beds, backs up at the end, and flows over the surface on each side.

The desirability of adopting one or more kinds of crop rotation has given rise to the alternating meadows. In these the fodder crop is preceded by a cereal, usually wheat, and followed by a crop of maize. Thus a common rotation is 1/2 year in wheat, 2 or more years in fodder crops and 1/2 year in maize. When the clover and grass is plowed under, the sods are gathered and carried in baskets to the compost heaps to be treated as in the case of compost for marcite meadows.

58. Irrigation in Spain.—The Kingdom of Spain contains a land area of 127,500,000 acres of which nearly 50,000,000 acres are cultivated and of this about 3,500,000 acres were irrigated in 1924. Owing to the low annual rainfall of the central and eastern parts, the warm, dry summer and the increase in population, irrigation is becoming of great economic importance. When one considers that the great central plateaus receive on an average only 9 inches of rainfall in winter and 1 inch in summer and that the lower coastal plains of the Mediterranean, while receiving slightly more winter precipitatio , have even less in summer, it is surprising that Spain is content with an irrigated area of 3,500,000 acres when a water supply is available for 15,000,000 acres. The need of irrigation is further shown by the low value of dry land compared with the high value of irrigated land. According to Rafael de la Escosura, dry farming land in the valley of the Ebro has a value of $16 to $20 an acre while similar land when properly prepared for irrigation and having a good water right is worth from $118 to $197 an acre.

Since 1900, well-directed and successful efforts have been made on the part of the state to increase the value and productivity of dry lands by constructing large irrigation systems at government expense and charging a low water rental to landowners. The most notable of these systems is known as the Canal de Aragón y Cataluña which was designed to irrigate 247,000 acres. The main canal of this system was begun by a private company, in 1851, but after $5,000,000 had been expended the company was unable to complete the project. Accordingly Baron de Romaña, who acted as the chief intermediary between the

owners and the state, finally succeeded in having the project undertaken and completed by the state. The success which has attended this enterprise since 1906, when water was first used, amply justified the state in undertaking its completion. In 1906 the area irrigated was 14,800 acres and in that year both irrigated and non-irrigated land under the system produced 1,465,000 bushels of grain. In 1914, 8 years later, the area irrigated had increased to 136,850 acres and the total production of grain on both dry and irrigated lands amounted to 3,780,000 bushels. It is estimated that when the entire acreage is irrigated the annual profit will be close to $3,000,000.

By comparing the tariffs adopted by both state and company canals as given below it will be seen that those of the state canals are much lower.

Canals	Cost of water	
	Pesetas per hectare	Dollars per acre
State canals		
Right bank of the Llobregat	25.75	2.03
Aragon and Catalune	4.00	0.32
Irrigation of upper Aragon	4.00	0.32
Imperial Canal of Aragon	7.50	0.59
Company canals		
Infanta	412.50	33.53
Tauste	86.00	6.69
Urgel	52.00	4.10
Right delta of the Ebro	47.00	3.70
Left Delta of the Ebro	47.00	3.70
Gaudiaro	56.00	4.40
Henares	86.00	6.69
Acequia of the Jarama	25.00	1.90

In addition to those named there are a number of other canals in the Ebro valley and a multitude of small diversions. From Logrone to a little below Saragossa, a distance of about 130 miles, the irrigated areas adjacent to the river and its affluents are numerous and extensive. Simple dikes of loose stone, and sometimes *norias,* draw water from the river to supply the

canals. The crops usually irrigated are olives, vines, cereals and garden truck.

Following down the Mediterranean coast a number of important irrigated sections are found in the vicinity of Valencia, Murcia, Lorca and elsewhere. In the strip of coastal plains extending from the delta of the Ebro River to Cape Nao, the available water supplies are quite completely utilized and in the southern part of this strip the irrigated areas are almost continuous, so that there is little to indicate that the country was once an arid waste. Surrounding Valencia is an area of 25,000 acres which is irrigated with water diverted from the Guadalaviar River. These canals were built in very ancient times, there being no authentic record of the date of their construction.

The section adjacent to Palma del Rio in southern Spain is watered by huge wheels identical with the *sakiehs* of Egypt. There are 20 of these wheels, most of which are over 30 feet in diameter. The natural current of the river is not strong enough to drive the wheels and, consequently, the stream is raised by simple dams producing a fall of about 4 feet. Each wheel and dam has its separate area to irrigate, the total area irrigated by the wheels being 500 acres. This section is devoted almost exclusively to citrus fruits and garden truck.

The unit of water measurement adopted at Valencia and in all the ancient irrigation communities of Spain is called a "*fila*" or "*hilo*," meaning a thread or filament of water. There is considerable difference of opinion as to just what this unit is. Some claim it is the volume of water which will pass through a square orifice with sides of 8.9 inches at a velocity of 35.6 inches a second. Others contend that the velocity should be 53.4 inches per second.

At Elche and Lorca a very curious custom prevails which consists of the disposition of the available water supply by daily auctions. At Lorca, in particular, this custom is very picturesque. The crowd congregates each morning in a large hall and at eight o'clock the crier calls out "In honor of the holy sacrament of the altar, who buys the first hila of Sotellana?"[1] Immediately there ensues excited and rapid bidding to which the president listens calmly until suddenly he indicates the successful

[1] Brunhes, Jean, "L Irrigation," Paris, 1902.

bidder and as suddenly quiet is restored. There is no appeal from the decision of the president and no one presumes to question his fairness.

Orange groves are found along the Mediterranean coast from Sevilla and Granada on the south to Barcelona on the north. In Alcira and Carcagente they are irrigated from April to October every 8 to 15 days about 2 inches being applied at each irrigation, and are also irrigated in winter if the ground becomes very dry. At Orihuela, however, no water is applied in winter and only at intervals of 20 days during the summer. The water is applied to a square basin around each tree, being supplied from a furrow running alongside. No water is applied to the surface of the ground outside of these basins.

Grain fields are rarely irrigated by flooding and then only between borders. If the ground is very dry previous to sowing winter grain in the fall, an irrigation is applied in October or November. One more irrigation in March or April will usually suffice to mature a crop but in extremely dry years another light irrigation is applied before the heads fill.

Corn is planted after the grain is harvested and matures in a little over 3 months. In a month or a little less after planting, the ground is plowed and ridges are formed, leaving the plant at the edge of the ridge. The corn is irrigated in 20 or 21 days after the hilling and at intervals of 8 to 15 days thereafter, the number of irrigations varying from four to eight according to the soil.

Alfalfa is sown in ridges and irrigated by the furrow method or broadcasted in beds 20 to 25 feet square and irrigated by lateral percolation from ditches surrounding them. In Alcira alfalfa yields twelve crops a year and in other sections five to seven crops. It is irrigated every week during hot weather and every 10 days during the remainder of the season.

The average cost per acre for preparing land for irrigation in the northeastern provinces of Spain is about $20. This not only includes leveling but the necessary farm ditches. This cost is based on labor at 60 cents a day and a work horse and man at $1.60 a day.

59. Irrigation in France.—The area of continental France including the recovered provinces of Alsace and Lorraine is in round numbers 136,000,000 acres, of which about 68,000,000

acres are cultivated. Of the cultivated area about 6,000,000 acres are irrigated.

The irrigation of native meadows in the center and north of France is a distinctive feature. For such, the water supply is derived from nearby streams and no long canals or costly structures are required. Even in the valley of the Rhone and throughout the Mediterranean provinces where irrigation is more generally practiced to increase the yield and quality of a large variety of crops, there is no large system corresponding to the Cavour canal of Italy or the Aragon and Cataluna canal of Spain. The bulk of the canal systems are of medium capacity, seldom carrying more than a few hundred cubic feet per second. Of these the following may be named:

Name of Canal	Stream from Which Water Is Diverted
Gignac	Herault
Vesubie	Vesubie
Saint Martory	Garonne
Verdun	Verdun
Pierralatte	Rhone
Beaucaire	Gardon
Forez	Loire

In addition to those mentioned, there are several medium-sized canals which divert water from the River Durance such as the Carpentras, Châteaurenard, Saint Mitre, Manosque and Marseille.

Some idea of irrigation canals and of irrigation conditions generally in France may be had from a brief description of one that of the Gignac canal[1] built in 1879.

The Herault River, having its source in the high Cevennes, has a minimum flow of several hundred second-feet and a large flood flow. In the narrow, rocky gorge above the plain of Gignac a masonry weir was built to divert the flow of the river into the canal. This canal has a maximum capacity of 177 second-feet and at a point 3 miles or so from the intake is diverted into two main branches, one of which extends over a distance of 18 miles and the other 12 miles. The irrigated area comprises 10,375 acres and the total cost of the system was $831,000, of which the

[1] See article in *Genie Civil*, Oct. 5, 1907 by Francis Marre.

government paid $273,000 as a subvention. The balance of the funds used was borrowed from capitalists to be repaid in 50 years, the government guaranteeing an interest rate of 4.65 per cent.

The founders of the company, that is to say, the farmers who were the original subscribers, pay an annual rate of a little more than $1.70 per acre for the water used, the duty of water being fixed at about 3 1/3 acre-feet per acre. Those who have joined the company since its organization pay rates about 25 per cent. higher than the originators. The receipts based on the foregoing rates suffice to cover the cost of operation and maintenance and provide for the necessary sinking fund.

This canal was built at the time when the phylloxera disease was devastating the vineyards of southern France, and one of the main purposes sought was to secure water to submerge the vines during the dormant season. Since then the vineyards have been reset with American stock and water for this purpose is now seldom required. Other and more important uses have been found, however, and the application of water to diversified crops under this and other canals has amply demonstrated the benefits of irrigation in the Mediterranean region. In the irrigated lands of the Southwest, fruit and vegetables assure large average returns and the products are not only shipped to the markets of France but supply those of other countries as well. The revenues from such crops as strawberries, peas, plums, cherries, apricots, peaches and flowers are particularly large.

60. Irrigation in Russia.—The data herein given concerning this country apply to conditions as they existed during the early period of the World War. Since that time there has been retrogression in agriculture as well as in other industries and the figures giving areas irrigated no longer apply.

Russia may be divided geographically as regards irrigation into: Turkestan, Crimea, Trans-Caucasia, southern and southeastern Russia and Siberia. Since conditions as to soil, climate and crops differ widely in these various sections they will be discussed separately.

Turkestan.—The climate of Turkestan is semitropical and is very favorable for agriculture, a great variety of crops being grown. The total annual rainfall in some sections amounts to only 2.4 inches while the evaporation is thirty-six times as great,

so that no crops can be grown without irrigation. The irrigation of parts of Turkestan dates back to a very remote time.

The diversion works in many cases consist of dams thrown across the bed of the river of the following types:

Sipoys.—A *sipoy* consists of a tripod made of logs and held together by means of horizontal frames. This tripod is placed on the bottom of the river and weighted down with boulders, the frames being bound together with brushwood. A row or several rows of tripods, with the spaces between the legs filled with brushwood, reed and stone, constitutes the dam.

Ishack.—An *ishack* is a modified form of *sipoy* and is constructed in the shape of a long wooden horse with numerous supports, the spaces between being filled with reed and brushwood.

Carabur.—A *carabur* consists of a large bamboo pile about 27 feet long and 7 feet thick, weighted down with rock. This pile is tied together with reed and is anchored to the stakes driven into the river bed and into the bank. Several rows of such piles constitute a diversion dam.

Such dams are gradually being replaced with modern structures. In most of Turkestan, however, the diversion works consist of temporary structures which are carried away at each big flood.

In Trans-Caspia, where the surface supply is very scarce, the underground water is utilized, the water being collected in subterranean tunnels called "*kiares-is.*" This method of obtaining water has been extensively developed in some sections, the number of *kiares-es* in one province exceeding 12,000, some of which are 6 1/2 miles long.

Rice and alfalfa are irrigated by the check method. Most other crops are irrigated from furrows, but subirrigation from deep furrows is also practised.

Few measurements of the amount of water applied to crops have been made. In one experiment it was found that approximately 2 acre-feet per acre was used on alfalfa yielding 7.7 tons. For cotton, experiments showed that the application of a little more than 1 acre-foot per acre was the most beneficial.

It is estimated that 13,500,000 acres of land can be eventually irrigated in Turkestan. This is more than twice the present area under irrigation.

CRIMEA.—Artificial watering is practiced almost exclusively in the southern mountain section of the Crimean peninsula. This is an important fruit-growing section, apples, pears, quinces, cherries, plums, peaches, and grapes being grown successfully under irrigation.

The water for irrigation is taken from rivers, springs, wells and from stored flood water. The diversion works and canals are very crude. The dams, in most cases are of a type called "*aric-bash*," being a fence placed obliquely across the bed of the river against which is piled a mixture of clay, manure, branches, etc. The usual height is about 3 1/2 feet and the length varies from 35 to 350 feet. These dams are, of course, washed out by each flood. In the lower parts of the river, where conditions are somewhat more favorable, due to a more sluggish current, a modification of this dam is found. This consists of two fences placed at right angles to the stream about 3 1/2 feet apart and 7 feet high. The space between is filled with small stones and the fence on the downstream side is supported by a pile of stones. During floods this dam may be partially destroyed but the framework usually remains.

Water wheels, propelled by animal power, are used in the lower and middle valleys. The average diameter of these wheels is 21 feet. One wheel turned by a team of horses will raise 137 gallons (50 *vedros*) per minute through a height of 17 1/2 feet. There are about 200 wheels of this type in Crimea.

Another lifting device, the "*noria*," more durable and more efficient than the Tartar wheel described above, consists of an endless chain running over a cast-iron drum to which are attached metal scoops. The drum revolves on a horizontal shaft and the power is communicated to it through a pair of bevel gears on one end of the shaft. The efficiency of the wheel is 80 to 86 per cent. The *noria* lifts not less than 183 gallons (662/3 *vedros*) per minute through a height of 17 1/2 feet. There are about 250 of these in operation in Crimea.

In addition to these a great variety of pumps driven by internal combustion engines have come into use; also windmills. In all about 12,150 acres are irrigated by pumped water.

Wild flooding and the basin method are the two methods most commonly employed. In flooding pastures the water is applied

to a depth of from 0.56 foot to 2.1 feet and is kept on for 3 or 4 days to 2 weeks. Orchards are irrigated by scooping out saucer-shaped basins around each tree and running water into these basins in succession down each tree row. After each irrigation the crust formed in the basins is broken up with a hoe. Orchards are watered once a month from May to August.

Tobacco is irrigated by furrows made with a hoe and run parallel to each other 2 1/2 feet apart. The most skilful irrigators can water about 2.7 acres per day by this method.

The measure of water is the "*czapka*" (meaning hoe) which is sometimes taken as the quantity of water that flows through a channel having a cross-section equal to the blade of a hoe. Another definition is the amount of water that can be successfully handled by one man using a hoe. The generally accepted definition, however, is a quantity of water equal to 30 to 40 *vedros*, or 1.85 to 2.45 cubic feet per second. The established practice is to use one *czapka* of water per day for each *dessiatine* (2.7 acres).

In irrigating gardens and tobacco the general practice is to irrigate whenever water can be obtained, the oftener the better. When water is abundant this amounts to two irrigations per week.

Trans-Caucasia.—Irrigation in Trans-Caucasia is confined to the eastern part of the country. This section consists of plains sloping gently toward the Caspian Sea and 1,940,845 acres are irrigated from 5.946 canals and ditches. The area irrigated in Trans-Caucasia increased 38 per cent. from 1905 to 1914.

The streams are fed from melting snows in the mountains so that there is an abundant water supply during the crop-growing season. In addition to the streams, water is obtained from springs, reservoirs, artesian wells and from other underground sources. The underground water is developed by means of subterranean galleries as described in the section on Turkestan.

The principal crops grown are grain, rice, cotton, mulberry trees, grapes and orchards. The irrigation period extends from the latter part of March until August or September, the greatest need for water coming in the period from March to June, which fortunately is the period of high-water in the rivers.

The only unit of water measurement recognized in Trans-Caucasia is the "bash" or the head of water which can be handled

economically by one man, which corresponds to the "irrigating stream" used in Utah. This has been accepted as the legal unit of measure and is taken as equivalent to 25 second-liters or about 0.8 cubic foot per second.

There are three large irrigating systems in Trans-Caucasia, the Karaiay-Steppe, the Ardsian Steppe and the Mugan Steppe. The first-named irrigates about 41,495 acres. The system consists of a main canal 12 miles long, a branch canal 3 1/2 miles long, and 16 distributaries. The Ardsian Steppe system irrigates about 27,000 acres of land. Its main canal is 24 miles long and the total length of the distributaries is 26 1/2 miles. The system cost about $260,000.

Southern and Southeastern Russia.—The annual rainfall in this section does not exceed 19.5 inches and in some places is less than 7.8 inches; consequently irrigation is necessary, or at least highly beneficial, to all this section. Irrigation, however, can only be accomplished after the expenditure of considerable money, for the reason that most of the large streams, such as the Volga, Don, Dnieper, etc., flow in deep channels and with gentle slopes. Consequently most of the farmers content themselves with the meager and uncertain returns from dry-farming with its frequent droughts, low yields, etc.

One of the largest irrigation works in this section is that built by the government on the Soliana Kuba River. It consists of a reservoir on the river having a capacity of 3,780 acre-feet (480,000 cubic *sagene*), two main canals, and one branch canal supplying water to about 5,600 acres of land.

The crops raised are rye, wheat, oats, barley, sunflowers, corn and forage. These crops are all irrigated by the same method, described as follows: The water from the irrigating canals flows through cuts in the embankments over the irrigated section, covering them with a layer of water. Banks 210 feet apart are placed in the direction of the horizontal slope on each section. The banks regulate the distribution of water over an irrigated section.

According to the data secured by the Kosticher experiment station, alfalfa required 183 cubic sagene of water per acre or a depth of 0.52 foot at the first watering and a depth of 0.44 foot at the second. Oats require 0.56 foot, wheat 0.55, and potatoes

0.88 to 1.16 in two irrigations. These measurements were made at the borders of the fields irrigated. Winter crops are watered twice in autumn after seeding, and once in the spring. It is believed that the average water consumption for the entire valley is not less than 0.88 foot in depth over the surface.

The average yield of alfalfa is 700 *puds* per *dessiatine* or 3.2 tons per acre in three cuttings.

The annual cost of upkeep of the system amounts to 900 rubles ($464). The cost of irrigation where the furrow method is employed is $0.57 per acre.

Where water is pumped for irrigation, the method of application to the fields is as follows:

> The whole field is divided by furrows into squares and right triangles. The area inside of each such square or triangle is separated by means of banks into irrigating sections, each section being an aqueduct to an irrigating furrow. The sizes of these sections vary from 10 1/2 to 35 feet. The water admitted from each furrow into the section is left there till the soil gets fully saturated and then is drained into the next section.

By this method one skillful irrigator can take care of 1.35 acres a day.

SIBERIA.—The climate of Siberia is very dry, the average rainfall never exceeding 19.5 inches and in some sections being as low as 3.9 inches. However, the evaporation is small so that crops can be grown without irrigation in many sections.

The irrigated area in Siberia amounts to about 216,000 acres. The crops grown are grain, cucumbers, melons, fruit, and some alfalfa. The methods of irrigation are very crude.

THE PRINCIPAL FEATURES OF THE WATER LAWS OF TRANSCAUCASIA.—All flowing waters not originating and ending on any property belong to the public and can be used in either of the following ways: (*a*) for domestic purposes, (*b*) for irrigation, and (*c*) for industrial purposes.

Every landowner is obliged to give a right-of-way, for which he is compensated according to valuation, for canals conveying water for the above purposes and for carrying waste water from the irrigated lands.

The priority of the rights to the water is determined according to their acquisition. The amount of the water to be used is determined according to the actual use. Every farmer using the

water has to bear either by money payment or by labor part of the expenses connected with the maintenance and repairs of the canals and operation of the system.

To facilitate the carrying out of the provisions of the law the whole of Trans-Caucasia is divided into water districts. For the decision of all questions concerning irrigation, the landowners of each district elect three persons as "representatives" for a term of three years. These men appoint a so-called "district water-superintendent" who is in charge of the distribution of water in the district.

All persons using the water of a canal elect an overseer or ditch tender for this canal. If among the parties using the water there are towns and villages, the inhabitants of each elect a man to distribute the water among them.

An hydraulic engineer for each district is appointed by the government to determine all technical questions. All above-mentioned elective officers are required to carry out strictly any directions concerning engineering matters given by the hydraulic engineer. Once a year all hydraulic engineers meet at Tiflis, the principal city of Trans-Caucasia, for the discussion of all technical questions affecting their respective districts.

At the head of the water-control system of the whole country of Trans-Caucasia stands the "Water Inspector of Trans-Caucasia," who is responsible to the Minister of Agriculture. A consulting lawyer or "jurisconsult" and a technical bureau are attached to his office. The inspector presides at the meetings of the hydraulic engineers.

The whole official organization can be put into operation in a district only after a detailed determination of the water rights of the different persons, towns and villages of the district. This determination is made by various district boards and one main board, sitting when required.

The district boards, composed of the local judge and the above-mentioned three representatives, determine the water rights according to the actual needs of the communities, taking into consideration written and oral testimony. All sessions of the district boards are public and all parties interested are heard,

The decisions of the district boards are sent to the water inspector, who, after having them examined from the legal and

technical sides, refers them, with his own opinion, to the main board.

Over this main board presides one of the judges of the Superior Court of Tiflis. This board is composed of the jurisconsult, an officer appointed by the Governor General of Caucasia and one of the hydraulic engineers.

Complaints of the decisions of the district boards can be filed with the main board and complaints against the decisions of the latter can be brought before the First Department of the Senate (the Supreme Court of Russia). If the complaints are found justified, the decision can be reversed by the Senate and ordered to be revised again by the main board.

Appeals to the Senate do not prevent the execution of the decision of the boards.

61. Irrigation in Egypt.[1]—Without irrigation there could probably be no Egyptian people, certainly no civilization in Egypt. The influence of irrigation pervades Egyptian economics, politics, social life, agriculture, legislation and even religion.

All of the water used for irrigation in Egypt is taken from the Nile or pumped from the underground supply. The Nile is a remarkable river in several respects. Extending from south latitude 4° to north latitude 31.5° the basin of this river lies in a greater variety of climatic regions than any other river in the world. The Nile drains nearly the whole of northeastern Africa, comprising nearly a million and a quarter square miles, but only half of this area contributes any water to the river. The mean flow of the Nile at Assuan for a period of 20 years is 107,350 cubic feet per second, the maximum recorded flow is 441,250 cubic feet per second and the minimum 14,120 cubic feet per second.

In the annual report of the Minister of Public Works for 1915–1916, the total area irrigated in Egypt was for the year previous 7,862,784 *feddans* or 8,161,570 acres, a *feddan* being equal to 1.038 acres. About 60 per cent. of this area was in lower Egypt and the remainder in upper Egypt. The summer crops in both lower and upper Egypt consisted of rice, maize,

[1] This article is based for the most part on the following works: "Egyptian Irrigation," 3d ed., Willcocks and Craig; "Egyptian Irrigation," C. T. Johnston, and *Report* of the Minister of Public Works for 1916.

cotton and sugar cane, the flood crops were rice and maize, while the winter crops were wheat, beans, barley, clover and onions.

There are 1,392,000 landowners in Egypt owning 5,464,000 acres, with a mean holding of 3.9 acres. The number of owners of less than 5 acres is 1,247,000, holding 1,370,000 acres—a mean holding of 1.1 acres. There are 12,410 owners holding 50 acres apiece or 2,460,000 acres in all—a mean holding of 200 acres. The population of Egypt in 1907 was 11,287,359, or 1.47 person per acre. Cultivation increased 13 per cent. from 1897 to 1907, while the population increased 16 per cent.

Basin Irrigation.—Two systems of irrigation are practiced side by side in Egypt. The ancient or basin system is confined to half of upper Egypt, and the modern or perennial system is employed on the remaining half of upper Egypt and the whole of lower Egypt. The perennial system applied to suitable lands is more profitable than the basin system, but depends on the summer supply of the Nile, which is both limited and irregular in quantity. To reclaim waste lands, improve deteriorated lands and renew old and fatigued lands, the basin system, which has come down from the Pharaohs, is the best. To develop good lands and make them yield their maximum when skilfully handled, the perennial system has undoubtedly the advantage.

Considering the times of flood and low supply, the climate of Egypt, etc., no better system than the basin method could have been devised. If the floods had come in April or May and been followed by a burning summer, or if the autumn floods had been followed by the frozen winters of Europe or the warm winters of the Sudan, basin irrigation would have been a failure or a moderate success; but given Egyptian climate, basin irrigation has stood without a rival for 7,000 years. By this system the direct labor of cultivation is reduced to an absolute minimum.

Basin irrigation holds the flood waters for some 45 days per annum over the whole of the valley. The water is in places 3 meters (9.84 feet) deep and in others only 30 centimeters (0.984 feet), the average depth being 1 meter (3.28 feet). The thorough saturation of the subsoil caused by basin irrigation provides a supply of underground water which can be drawn upon by pumping to mature certain crops and for growing others.

The basins have an average area of 7,000 acres. Where the valley is narrow they average 2,000 acres each and where it is wide 20,000 acres, while some of the tail basins are 40,000 acres in extent. Each canal has seven or eight basins depending on it, of which the last is always the largest. There are masonry regulators at the canal heads, at each crossing of the cross-banks and at the tail-escapes into the river. In the more perfect basins, the canals and escapes syphon under one another and overlap and supply each other's deficiencies, so as to meet the requirements of every kind of flood which Egypt can experience. The cost of basin irrigation in Egypt for basins of 10,000 acres may be taken at £3 ($15) per acre.

The filling of the basins begins ordinarily about the twelfth of August and in the southernmost basins is completed by the first of October when the escapes are opened and the water discharged back into the Nile, ordinarily by Oct. 15. If the Nile is still high when the time for emptying comes, there is no recourse but to allow the water to remain until the river lowers, but this very seldom occurs. If the flood has not been sufficient to fill all the basins completely the upper basins are drawn off to supply the lower ones.

The basin dykes have an average width at top of 6 meters (19.68 feet), a height of 3 1/2 meters (11.48 feet), and a slope of 1 to 1. A few of the transverse dykes are riprapped with stone on their northern slopes to break the force of the waves. The villages within the basins are on artificial mounds protected with stone. Communications between villages are kept up by means of boats or the dykes during the inundation.

Perennial Irrigation.—About the year 1820, Mohamed Ali Pasha changed the irrigation system of lower Egypt by excavating a number of deep perennial canals capable of discharging the low-level summer supply of the Nile. This allowed the cultivation of cotton during the summer and thus introduced cotton on a large scale in Egypt.

As the area under perennial irrigation increased it became evident that the summer flow of the Nile was unreliable unless supplemented by storage. Accordingly, in 1888, steps were taken to build control works on the river to protect against

drought, and later the great Assuan dam was built, impounding approximately 2,000,000 acre-feet of water.

In all perennially irrigated tracts the year is divided into three seasons. The summer crops are sugar cane, cotton, rice, millets, vegetables and orchard fruits; while clover is irrigated up to June. The summer is followed by the flood season, when the whole country is irrigated. The flood crops are millets, maize and rice. The third season is winter, when the crops are clover, wheat, beans, barley, vetches, etc. The flood crop of maize is the staple food for the whole agricultural population.

Since 1901, the whole of the summer discharge of the Nile has been utilized in perennial irrigation.

The area provided with perennial irrigation by the state covers 4,064,000 acres, of which 964,000 acres is in upper Egypt and 3,100,000 acres in lower Egypt.

One of the most important perennial irrigation areas is the Fayum in lower Egypt. The Fayum, like parts of the Imperial Valley of California, is an inland depression with a lake called Birket Harun located in the northwestern part next to the Libyan desert, the surface of which is 33 feet below sea level. The only connection between the lake and the River Nile is an artificial canal. During the reigns of Amenemhat I and his successors of the twelfth dynasty, this lake must have covered fully ten times its present area, and, being controlled by sluice gates, formed the famous Lake Moeris, which served as a regulator for the high and low floods of the Nile.

Since the Assuan reservoir was completed 405,000 acres of basin land have been converted to perennial irrigation. There remains under basin irrigation an area of 995,842 acres.

In 1912, it was estimated that the total number of water wheels or *sakias* on wells in the basins was 40,600; also 740 oil engines with a total horsepower of 11,470. The greater part of the land supplied with water in this way (240,330 acres) is devoted to sugar cane and sorghum, and the remainder to cotton.

Large sections of the basin areas have been enclosed by subsidiary dykes and cultivated with sugar cane and cotton. Such lands are irrigated by pumps deriving water from the Nile or wells in the basins. The natives generally pump their water by means of *sakiyehs* (Fig. 109) operated by oxen or by *shadoufs* worked by

men, although in some cases deep wells are bored by companies and the water is pumped and sold to the natives.

Cotton is irrigated at planting time and about 30 to 35 days thereafter the second irrigation is applied, subsequent waterings being at intervals of about every 15 to 18 days. In all, eight waterings are given prior to the time the flood arrives. After the flood, four more irrigations are given. The total amount applied per acre is 4,400 cubic meters (about 3.5 feet in depth over the surface).

FIG. 109.—The sakiyeh for lifting water in Egypt.

For the summer watering of rice the water is changed every 2 to 3 days during the first fortnight, then every 4 to 8 days for the next 6 weeks, further waterings occurring every 8 to 10 days.

Wheat and barley are irrigated at time of sowing, again 40 to 45 days later, while a third irrigation is applied at flowering time.

Sugar cane is watered 15 to 16 times, receiving in all 8,800 cubic meters (7 acre-feet) of water per acre.

62. Irrigation in North Africa.—It was General Lyauty who said "North Africa is to our French race what the far West is to the people of the United States, that is to say, the most desirable field for the display of energy, rejuvenation and fruitfulness."

Upon what realities are these hopes founded and what does Tunis, Algeria and French Morocco possess which leads far-seeing Frenchmen to believe that in time the mother country will derive lasting benefits from its colonial possessions across the Mediterranean?

Tunis, or Tunisia, as it is sometimes called, is the smallest of the three countries, its area being about equal to New England with Maine excluded. Algeria is divided into Algeria proper which borders on the Mediterranean and the Territory of Algeria which extends southward into the Sahara desert. The first is about the size of the state of California, and the second is larger, while the area of Morocco equals about three and one-half times that of New England. These three dependencies of France extend from east to west in the order named over a distance of 1,500 miles and are chained together by the Atlas Mountains. This mountain range and the table lands which support it increase in altitude from east to west being about 5,000 feet in Tunis and nearly 10,000 feet in Morocco, with occasional peaks rising several thousand feet higher. Mt. Tamjurt in Morocco, if placed by the side of our Pike's Peak, would overtop it by several hundred feet.

The history of this part of Africa and more especially of Tunis and Algeria, extend far back into unrecorded times. Dr. A. Carton says:

> In that country there was not a spring that was not diverted nor a ravine that did not have several dams. I saw, for example, in an exceedingly arid plain, a slight depression where the earth, retained by a very ancient dam, held a half score of enormous olive trees.

As a matter of fact, the most ancient of these irrigation systems were not built by the Romans. Irrigated agriculture was successfully carried on by the native Berbers for centuries before Scipio's legions destroyed Carthage. The Romans merely improved and enlarged the native works.

The topography and climate of the country are such that a wide range of products can be successfully grown. In these respects it resembles the United States. There is the same wide diversity in crops and climate between the palm-studded oases of the Sahara and the perpetual snows of the higher Atlas range that exists between the Imperial Valley of California and the

higher altitudes of the Rocky Mountains. Between these wide extremes one finds the native grasses, cereals, fodders and vegetables of the uplands; the vine, fig, olive and tobacco of the more temperate zone; the orange, tangerine and banana of the subtropical territory and the data palm of the desert. The potentialities of this country are so great that the time may soon come when Europe will depend on North Africa for its subtropical fruits and winter vegetables in much the same way that the central and northern portions of this country depend on Florida, and the Southwest for such foods as now reach our tables.

There is, however, a great natural drawback to successful farming in North Africa. The rainfall is not only deficient and unevenly distributed throughout the year but when it does come it is apt to be in the form of sudden downpours. In consequence, part of the country is as arid as Nevada, other portions resemble California in having a fairly heavy rainfall in winter with little or none in summer, while still other portions can depend on a fairly adequate supply to mature crops.

The native Berbers did not possess the means nor skill to build high dams, but they made up in numbers what they lacked in height or capacity. By means of a multiplicity of small dams of earth and stone, the run-off was held back in small basins on the sides of hills and these pioneer works were so well planned and executed that hydraulic engineers of France are today restoring these ancient ruins to serve the same purpose.

63. Irrigation in South Africa.[1]—Long before the advent of the white races in South Africa, the irrigation of land in a primitive way had been carried on by the natives. Traces abound of simple means by which water had been stored and led to small patches of cultivated soil for the production of crops, but the continual feuds amongst the indigenous tribes of savages kept the land in a state of unrest and in consequence only feeble attempts at cultivating were possible.

When the Cape of Good Hope became permanently occupied by Europeans, irrigation was resorted to for the production of foodstuffs. In the early stages of development, a small area adjacent to the coast was occupied with gradual extensions in

[1] Based largely on statements prepared by T. Early Scaife, Superintending Engineer, Irrigation Department, Pretoria, Union of South Africa.

land. This pushing forward step by step, away from the coast, has been, and still is, a characteristic feature of agricultural development in South Africa.

During the past 24 years, progress in irrigation has been continuous and rapid. Prior to 1900, the irrigation works resembled those first built in this country. Water was supplied to near-by lands by crude dams and short ditches. During this period, also, efforts were made to enact suitable irrigation laws.

Thus, in 1877, an act was passed enabling communities to create irrigation districts and irrigation boards and in 1899 another law was passed creating water courts. These and other acts were applicable to only one province, however, and when the confederation of the four provinces of The Cape, Free State, Transvaal and Natal took place in 1910, it was necessary to frame general irrigation laws for the Union. This was done in the Water Act of 1912, which embraced three main features, *viz.*, Irrigation Boards, River Boards and Water Courts.

Irrigation boards have been a decided success throughout the Union. From a commencement made with the Breede River Irrigation Board in 1899, their growth has been rapid and 4 years ago nearly 100 had been formed. Three or more landowners may form themselves into an irrigation board for the construction and maintenance of works. The usual procedure, after organization, is for the board to apply to the Irrigation Department for the services of an engineer to prepare plans and estimates of cost of the proposed works. The board may employ an engineer to do this work but if so, the plans must be submitted to the government for approval. On approved projects, Parliament grants loans usually for 40 years at about 5 4/5 per cent. covering the estimated cost of the works together with interest, compensation and other charges during the period of construction and for 2 years after the works are completed, and in operation.

This wise policy enables farmers who have contracted for a water supply to devote their means and energies to placing their land on a productive basis. Enterprises undertaken by irrigation boards are meeting their financial obligations with ease. The more so, since many of them were financed at a time when construction costs and interest rates were low. The tendency at present is to undertake larger and more ambitious projects and,

from an economic standpoint, these may not prove so remunerative. Minor projects costing less than $150,000 can be sanctioned by the Minister of Lands and Irrigation, but when the estimated cost exceeds this amount it is referred to Parliament and is investigated by a special committee appointed by that body.

Thus far only three River Boards have been formed, the chief of which is the Breede River Conservation Board, which controls the major portion of the Breede River Valley where extensive irrigation systems have been built during the past 20 years. Little water flows in the Breede River from December to March and the main purpose of the Conservation Board was to store water for the various systems for use during this shortage. Within the jurisdiction of the large board are several irrigation boards.

There are two Water Courts in the Union one located in Cape Town and the other in Pretoria. The Court is composed of three members; a judge who presides, a government irrigation engineer and a selected landowner. These itinerant Water Courts have large judicial powers and have performed excellent service in elucidating the many difficult questions arising from the storage, conveyance and division of water in an arid region.

The climate and soil products of the Breede Valley located about 100 miles to the north of Cape Town resemble those of southern California. The normal rainfall which occurs during the winter months is about 12 inches and alfalfa, vines and fruit trees both deciduous and citrus are successfully raised under irrigation.

That extensive semiarid territory known as the Karroo containing many hundred square miles resembles in some respects the Great Plains region of the United States in that the rainfall is erratic and the available water supply limited. During years of heavy rainfall the farmers are lulled into a sense of security which does not exist. Farming operations are extended, and population and stock increase far in excess of what the land is capable of maintaining during the lean years when the rains fail. Owing to the scarcity of water it is unlikely that more than a very small percentage of the good soils of the Karroo will ever be irrigated and the bulk of this vast territory must remain as at present, a pasture for sheep.

Irrigation in the Transvaal is still in its infancy. Owing, however, to the abundant resources in the way of soil and water and a favorable climate a large development may be expected in this province in the near future.

64. Irrigation in India.—India includes within its borders the highest mountains in the world and some of the mightiest rivers and greatest plains. Topographically it may be divided into three distinct parts: first, the Himalayas along the northern border; second, the plains of the great rivers; and third, south of the plains a tableland broken by many peaks and mountain ranges separated by broad and fertile valleys.

The Himalayas may be likened to the Sierra Nevada, bordering the eastern side of the great California valley, having the same general appearance of low, rolling foothills with the higher peaks so far back as to be scarcely visible from the valley. The highest peak is Mount Everest, 29,002 feet above sea-level, while peaks above 20,000 feet elevation abound.[1]

The principal rivers are the Indus, the Ganges and the Brahmaputra, all of which rise in the Himalayas; and the Godaveri, Cauveri and Kistna rising in the western Ghauts, a mountain range along the western seashore of the peninsula. Water for irrigation is diverted from all these rivers except the Brahmaputra.

The flood discharges of the various great Indian rivers are enormous. The Ganges in flood may discharge 1,350,000 second-feet, the Godaveri the same amount, while the Soane, one of the smaller rivers, having a catchment area of only 34,000 square miles, discharges 1,700,000 second-feet, equivalent to 50 second-feet per square mile of catchment.

By far the greatest part of the rainfall[2] of India is due to the southwest monsoon, which occurs between June and October. The later part of the cold weather and the earlier spring months are the times of the winter rainfall in northern India. The intensity of the rainfall varies greatly. The average fall of the whole of India is about 42 inches. Speaking generally, it may be said that the smaller the average rainfall of any tract, the

[1] Wilson, H. M., "Irrigation in India," *W. S. and T. Paper* 87, *U. S. Geol. Survey.*

[2] Buckley, R. B., "The Irrigation Works of India."

greater is the probability that the gross fall in it in any particular year will be below the average of a long series of years. When the annual rainfall is not over 10 or 20 inches crops cannot be grown without irrigation. On the other hand, in sections where the average fall is 70 inches, it is very seldom that any irrigation is required. Intermediate between these two conditions there is a tract of about a million square miles where irrigation alone can secure the country from an occasional loss of crops, although such a loss will never occur simultaneously over all the area.

Authorities differ regarding the area actually irrigated in India. This is probably due to the fact that large areas of land are provided with a water supply as a protection against drought which occurs only at intervals so that the cropped area irrigated varies from year to year. Another reason may be the fact that much of the land produces two or more crops yearly so that the acreage in crops is considerably larger than the area of land irrigated.

According to the most reliable information obtainable, the area actually irrigated in 1911–1912 was as follows:

By canals:	Acres
Government	16,820,827
Private	2,068,428
By tanks	5,364,200
By wells	10,408,424
Other sources	6,017,263
Total	40,679,142

The total length of canals in India is 42,352 miles, of which 12,497 miles were main canals and the remainder distributaries.

The irrigation works of India have been divided by Buckley into the following classes:

1. Major works:
   - *a.* Works of which the capital has been provided from borrowed money (productive works).
   - *b.* Works of which the capital has been provided out of the general revenues of India (protective works).
2. Minor works:
   - *a.* Works of which capital and revenue accounts are kept.

b. Works of which no capital accounts are kept.

There are 42 systems coming under major works (*a*). Before a project can be sanctioned under this class it is necessary that there should be good reason to think that it will provide a net revenue equal to or greater than the interest which the government has to pay on the money borrowed for its construction. The test, in fact, which is applied to all projects for works of this class, is a purely commercial one; it is considered that borrowed money should be expended only on works which are likely to be remunerative. According to figures compiled several years ago, 19 of the 42 major works (*a*) had not paid 4 per cent. interest on the investment, but the profits from the other 23 were sufficient to cover the deficiencies.

The major works (*b*) are eleven in number. They are the works generally known as "protective works" which will not stand the commercial test applied to the major works (*a*); that is, the net revenue derived from them is not likely to cover interest on the capital expended. They are designed as a protection against famine.

The minor works (*a*) comprise 85 systems in operation. Some of these works are old tanks and inundation canals which have been taken over, improved and worked by the British Government; others are new works entirely constructed by the British Government but which do not fulfill the conditions of the two classes of major works above described. The majority of this class of works were constructed before the system of constructing irrigation works from borrowed capital had been introduced, otherwise some of them would have been classed as major works (*a*).

The minor works (*b*) are extremely numerous and generally of small extent individually. The great majority of them are old works and there is no record of their original cost.

The amount of water required to mature the staple crops of India varies greatly with conditions. Many of these, such as the character of the soil, rainfall, transmission losses and the like do not differ from those of the United States. Again, the greater part of the irrigated portion of India resembles the Pacific Coast states in having a wet and a dry season in each year, with this difference, that in India the heavy rainfall occurs in summer.

Khareef crops, such as cotton, corn, indigo, and rice, are grown in the rainy summer season while *rabi* crops correspond to the fall-sown wheat of the West. In general more water is required for *Khareef* than for *rabi* crops. Thus, under the upper Ganges Canal, according to Buckley, the average depth of water applied to the former was 32 inches over the surface, while 20 inches sufficed for the latter.

The methods followed in preparing land and applying water and in the production of irrigated crops generally, differ in many essential features from the corresponding practice of this country. This wide difference arises from the small size of the average farm in India, the cheap labor, the lack of equipment, as well as land tenure and land surveys. Irrigation as practiced by the Hindoo farmers is not unlike Chinese gardening in the arid states of this country. Small irrigated plats, the absence of costly equipment, a large amount of manual labor and the exercise of skill as well as patience, characterize both.

65. Irrigation in Java.—The island of Java is approximately 670 miles long and has an average width of 82 miles. Through the middle of this elongated island runs a chain of mountains of volcanic origin, many of the craters still being active. The plains are composed for the most part of material brought down by the volcanoes.

The rainfall is governed quite largely by the monsoons, the west monsoon causing rains and the east monsoon giving rise to droughts. The heaviest precipitation, of course, occurs in the high mountains and becomes less as the lower plains are reached. The rainfall on the plains along the northwest coast is greater and starts earlier than on the northeast coast but the rains along the latter coast extend over a longer period. In general, the rainfall is heavier along the south coast than the north coast. The rainy season extends from October to May, February being the wettest month and August the driest. During the time of the east monsoon or dry period, the rainfall is sometimes very scant, little rain falling for several months in some years. The rainfall at Batavia, the seat of government, is 72.28 inches per annum and at Majalenka it is 175 inches. In the more elevated portions of the island the precipitation is even greater, but authentic records are lacking.

The island of Java lies wholly in the tropics, being a short distance south of the equator. The crops grown consist principally of rice and sugar cane, which are grown in the west monsoon, and maize, pulses, arachides, cassava, tobacco, indigo and cotton, which are grown during the dry period, since they require less water.

Owing to the shape of the island, the rivers have short courses and small watersheds. The largest are the Solo and the Brantas, having lengths of 325 and 190 miles, respectively. All the rivers have a general northerly or southerly course. The discharges of these rivers are extremely erratic. The Solo, for example, has discharged as high as 90,000 cubic feet per second while its minimum flow is 800 cubic feet per second. Nearly all these rivers bring down enormous quantities of silt during the floods, especially in the regions of active volcanoes.

The island of Java with Madura comprises about 32,500,000 acres of which 40 per cent., or 12,500,000 acres, are cultivated. The population in 1917 was 34,157,383 making it one of the most densely populated lands in the world. Notwithstanding this fact the people for the most part live in small villages and are engaged in agriculture. Batavia is the largest city, having a population in 1917 of 231,464. Each town or village constitutes a separate and distinct community, seldom exceeding 1,000 inhabitants, and when the population reaches a certain limit a new community is formed, which begins the development of new land. The population of Java nearly doubled between 1880 and 1905, due, in all probability, to the work of the Western rulers in utilizing the water of the large streams for irrigation, thus greatly increasing the productivity of the valley land.

The Javanese have practiced irrigation on their rice fields from a very remote time. Their systems are, of course, very crude, and they were only able to utilize the waters of small streams and wells, since they lacked the necessary technical knowledge and resources to make use of the water of the large rivers. Nevertheless, more than half of the area of irrigated rice fields in Java are supplied by native works.

The Netherlands Colonial Government, first represented by the East India Company, began taking interest in irrigation work as early as the eighteenth century. The first canal constructed

under government supervision was the "Oosterslokkan" built during the years 1739 and 1753. Since that time the Government has continued to take an active part in irrigation matters, but the greatest activity in the construction of works has taken place since the establishment of the Public Works Department, in 1854. A considerable part of the work has been done during the last 15 years and works are now under construction for the irrigation of about 415,000 acres additional. This work consists of repairing and reconstructing existing systems, many of which were of a very faulty design or of a temporary nature, and also in the construction of new works. There have been 11 large projects constructed by the government or in course of construction, costing from $300,000 to over $3,000,000 each.

The growth of the government participation in the construction of irrigation enterprises is evidenced by the fact that in 1885 there were 9 engineers and 12 surveyors employed, whereas, in 1914, the number had increased to 95 engineers and 136 surveyors.

The chief irrigated crops of Java are rice and sugar cane. There are roughly 4,000,000 acres devoted to rice on the island and of this 2,500,000 acres are irrigated, the remainder being what is termed "Providence" rice in the United States; that is, dependent on the natural rainfall alone. Rice is usually grown during the west monsoon but in districts where irrigation water is abundant during the east monsoon two crops are grown on the same land, one during each monsoon.

The rice seed is sown in nurseries where it is allowed to remain for 6 weeks. It is then transplanted in the fields. About one-tenth of the area to be planted is taken up by the nurseries. For the first few days after the rice is sown the beds are simply kept damp, after which they are entirely submerged until time of replanting.

Before the seedlings can be transplanted to the rice fields proper, the latter must be prepared for the purpose. The quantity of water required depends on the nature of the soil, the topography, the height of the ground water, and the rainfall. In some districts the soil needs very little water prior to planting so that only a few weeks need elapse between the time of plowing and planting. In other sections the ground is subjected to a

copious watering before plowing (Fig. 110) and a long course of treatment afterward, consisting of successive plowings, harrowing, and exposure to sun and air. The time required for such treatment is from 7 to 14 weeks.

After planting, further irrigation is needed for a time, the necessary quantity diminishing as the plants get older. No water is necessary after the heads begin to fill.

No attempt is made to plant an entire field at one time; in fact it is not uncommon to find a difference in the time of maturity of 6 to 8 weeks in a single field.

FIG. 110.—Ploughing in Java.

The second crop in importance is sugar cane, which is grown extensively in some localities and constitutes one of the chief export crops of the island. Sugar cane is planted any time from May to August. As a rule, the same piece of ground is planted once in 3 years. Irrigation is usually necessary only during the east monsoon.

The so-called "secondary crops," consisting of maize, tobacco, cassava, etc., are grown during the east monsoon. Less water is required for these crops than for sugar cane. In many districts the irrigation water is divided between the sugar-cane plantations and the secondary crops, the water being applied to the

sugar cane during the day and to the secondary crops at night (Fig. 111).

Non-irrigated lands yield from 50 to 55 per cent. of irrigated lands. The duty of water is from 20 to 30 acre-inches per acre.

According to the *Yearbook* for 1920 of the Netherlands East Indies, the irrigated and irrigable lands of Java are as listed

FIG. 111.—A patjol—an implement used extensively in Java and other parts of the Orient.

below. Sugar cane was grown on 403,000 acres of the irrigated land.

	ACRES
Irrigated areas where permanent works are in use	1,443,000
Irrigated areas where permanent works are in course of construction	741,300
Irrigated areas where permanent works are being prepared or under construction	422,500
Irrigated land, and land dependent on rain for which no plans have as yet been made	3,459,400
Total	6,066,200

66. Irrigation in Japan.—Japan proper is a little larger than Montana but has less arable land. At the close of 1920, there were 15,070,856 acres under cultivation of which 7,452,807 acres were irrigated. Rice is the only crop irrigated with the exception of a small acreage in rushes used for making mats. In the

warmer districts, the soil moisture resulting from rice irrigation aids in nourishing such after crops as barley, rape and clover. Regarding the water supply for the irrigated land, 65 per cent. is derived from direct stream flow, 21 per cent. from reservoirs and 14 per cent. from wells. As to the adequacy of the water supply about 19 per cent. of the irrigated lands has a deficient supply.

The unit of land measurement for statistical purposes is the *cho*, equivalent to 2.45 acres or about equal to the hectare. The most popular unit, however, is the *tan*, equal to one-tenth of the *cho*. The unit of water measurement as used by engineers is the "cho-shak," which means the quantity of water covered by a *cho* to a depth of 0.98 feet.

Through the courtesy of Ikuo Yahiro, Inspector General of Land Melioration in Chosen (Korea), the author has obtained the following information regarding land improvement organizations in Japan.

Japan has a Water Utilization Association Act, corresponding generally to the irrigation district acts of the western states, and also an act for the improvement of land by irrigation and other means.

Water Utilization Association Act.—No information is at hand as to the date of original passage of this act, but it was amended in 1908. Such an association may be constituted in any one of four ways:

1. By the Governor of the Province on his own initiative.
2. By the Governor on petition of five or more landowners.
3. By the Governor on petition of the country head (appointed by the Governor).
4. By the Governor on petition of the village head (elected).

In every case a committee is appointed by the Governor to make a contract and plan of operation. At a meeting of the landowners the contract and plans are determined by majority vote. The matter is then reported to the Governor, whose approval is necessary before the plan may be put into operation.

Landowners are members, but in case of associations for flood control, owners of buildings as well are members.

The head of the association is appointed by the Governor. The county head or village head is usually appointed to this

place. The treasurer of the association is the clerk under the county or village head.

Taxes in case of an association for irrigation are levied against the landowners only; but in case of an association for flood control are levied against owners of buildings as well. The assessment is usually at a flat rate. Sometimes, especially in case of flood control, the labor of association members is utilized, a member being allowed to employ someone to take his place.

The water utilization association is used mostly in case the farmers cannot agree, and in case the Governor considers that an association should be organized to accomplish the desired purpose.

Finances are handled through long-term loans by industrial banks.

IMPROVEMENT OF LAND ACT.—This act was passed in 1900 and amended in 1909, 1914, and 1919. A petition for the formation of an improvement district signed by one-half the number of landowners in the proposed district, representing two-thirds of the acreage and two-thirds of the value of the land, is presented to the Governor of the Province through the county head, the Governor organizing the district and reporting the fact to the general government. The minimum acreage permitted is about 12 acres. Improvement purposes include:

1. The completion or improvement of
   a. Irrigation and drainage works.
   b. Road changes, to straighten winding roads that exist through the irregularity of property lines. Sometimes the roads are built at the same time as irrigation or drainage canals and follow their banks.
   c. Farm boundary changes, to rectify irregular farm boundaries and make them more suitable for cultivating. Changes involve transfers of pieces of land from one neighbor to another in order to make rectangles. The largest unit is about 1 acre, the smallest 1 *tan* or one-fourth acre.
   d. Reclamation of land from the desert.
   e. Putting dry farms under irrigation.
2. Maintenance and operation of the works.
3. Invitation to settlers to come to the district.

Lessees under certain circumstances may become members, by agreement with landowners.

The Governor of the Province supervises the association. Engineering aid is given through the Governor, and funds for construction are borrowed from industrial banks upon public certificate as to feasibility. Loans run for 20 years, and bear 5.4 per cent. interest if over $15,000 and 5.9 per cent if under $15,000.

To June, 1922, there had been formed 12,206 associations, covering a total of 1,525,385 acres, with a total expenditure of $87,092,521, or about $57 per acre.

Certain forms of financial aid are given through the Governor to these organizations. Instead of increasing the taxes on land as it becomes better improved, the tax is held at its original rate for 40 years. In case of reclamation of land, land previously not taxed on account of having no improvements remains exempt from taxation for 60 years. Expert engineering advice and assistance is given through the Division of Land Improvement of the Province and through the Division of Melioration of Land of the Bureau of Agriculture of the general government. To aid in cost of constructing works, the government makes subsidies or donations to the province and the Governor of the Province combines such donations with provincial aid. In this way each province is able to assist such improvement associations at varying rates, ranging from 10 to 30 per cent. of the cost of construction.

Public Aid from General Government.—In addition to the financial aid to improvement associations indicated in the preceding paragraphs the Government of Japan gives financial assistance directly to improvement associations, to water utilization associations, and to individuals based upon the cost of construction of works, for the purpose of encouraging the improvement of land. This policy was initiated in 1919. It takes the form of giving not over 6 per cent. of the cost of construction each year from the beginning of construction until 4 years (or less in case of small enterprises) after the completion of the work, the 6 per cent. being figured on the total cost up to that year; in other words, it amounts to paying the interest on the bank loans during that period. An actual case was:

Year	Annual expenditure	Total expenditures to date	Government donation
First	$15,000	$ 15,000	$ 900
Second	15,000	30,000	1,800
Third	10,000	40,000	2,400
Fourth	5,000	45,000	2,700
Fifth	5,000	50,000	3,000
(Construction completed)			
Sixth	.....	50,000	3,000
Seventh	.....	50,000	3,000
Eighth	.....	50,000	3,000
Total	.....	$330,000	$19,800

CHOSEN (KOREA).—Chosen has a Water Utilization Association Act. It has no improvement district act, but has an act for the encouragement of improvement of land by both public and private works.

Chosen has an irrigated area of 3,778,030 acres, and an unirrigated cultivated area of 6,806,355 acres. The irrigated area constitutes, therefore, only about one-third of the total cultivated area, whereas in Japan proper it consists of fully one-half of the cultivated area.

WATER UTILIZATION ASSOCIATION ACT.—This act was passed in 1906, and amended in 1917. Formation is initiated by five or more landowners, who come together and draw up a contract and plan. Thereafter, a petition signed by one-half in number of landowners, representing two-thirds of the area and two-thirds of the value of the land, is presented through the county and province to the Governor General. Having permission to organize, the association may do construction work for irrigation, drainage and flood control. The petition is granted by the Governor General. The departments of Interior, of Agriculture, and of Public Works examine the petition and advise on it. Sometimes government engineers plan the works, but generally the association has its own engineer.

The head of the association is appointed by the Governor of the Province. There is a consulting board consisting of

elected members of the association, generally five to ten members. The head appoints the secretary, treasurer, engineer and other employees. There are sometimes two vice-chairman. The association constructs works and operates and maintains them afterwards.

Assessments are apportioned according to benefits. During the early years while more and more of the land is being put under irrigation the assessments of course vary, but after all the land is irrigated they are usually at a flat rate.

The association borrows funds from industrial banks upon Government certification of feasibility, loans running 20 years or more and bearing up to 8 per cent. interest.

There are (June, 1922) 34 associations in Chosen, containing 114,055 acres, with works constructed at a total cost of $9,115,085, or $80 per acre. The largest association contains 9,640 *cho* (23,618 acres) and the smallest 64 *cho* (157 acres). The maximum assessment in 1921 was $18.78 per acre, and the minimum $0.40 per acre. Operation and maintenance charges were very small in comparison with the charges for payment of principal and interest.

Act for Encouragement of Improvement of Land.—This act gives financial aid to associations and individuals for the purpose of encouraging the improvement of agricultural land by irrigation and drainage and the reclamation of land. Where it is possible to drain rice land after harvesting the rice crop, a winter crop of grain (wheat and barley) or forage can be produced; otherwise the land lies idle during the winter. Encouragement is given by this act to the winter drainage of rice land in order to make it available for further crop growth, as well as to the construction of irrigation works and to the reclamation of land from the desert or from overflow by the sea.

Under the act, the government donates to a minimum of about 72 acres, 20 per cent. of the cost of improving land by irrigation or drainage, securing additional water supplies, repairing works, etc.; or to a minimum of about 72 acres, 25 per cent. of the cost of putting dry land into rice culture and irrigation; or to a minimum of about 20 acres, 30 per cent. of the cost of bringing uncultivated land into cultivation, such as desert land, land needing protection from overflow by the sea, etc.

Aid given under this act to the year 1921 has affected the following areas:

Public work; that is, work done with advice and assistance from the government:	Acres
Reservoirs and river works	585,305
Reservoirs and river works repaired	126,910
Water utilization associations	103,660
Sub-total	815,875
Private work	20,090
Total	835,965

This constitutes about 22 per cent. of the total area irrigated in Chosen, which total is 3,778,030 acres. The other 78 per cent. has an insufficient water supply.

Aid by Provinces.—The various provincial governments in Chosen, as well as the Government General, have made donations toward repairing dams and reservoirs, for both public and private irrigation enterprises.

Duty of Water.—Experiments showed the average net duty of water for rice for the period 1908 to 1916 to be 33 inches. During the period covered by the measurements each year (about 100 days) the average rainfall was about 20 inches, evaporation 20.4 inches and percolation loss 16.6 inches. The average annual rainfall near the experiment station is 45.9 inches and average annual evaporation 46.9 inches. Throughout Korea the maximum annual rainfall is 59.7 inches, minimum 42.1 inches, and average annual 50.6 inches; maximum annual evaporation is 58.3 inches, minimum 29.3 inches, and average 40.8 inches.

Formosa.—Although rice is practically the only crop irrigated in Japan and Korea, sugar cane is irrigated in Formosa.

67. Irrigation in China.—China proper, divided politically into eighteen provinces, is nearly ten times larger than California. The dependencies of Manchuria, Mongolia, Chinese Turkestan and Thibet contain nearly double the area of China proper but the population of the dependencies is less than 19,000,000, while that of China proper is about 411,000,000.

The massive and elevated tableland of Thibet forms the center or backbone from which all mountains in China branch off. This is likewise the source of the largest river systems of which the

chief are the Hwangho in the north and the Yangtze-Kiang in the south.

The area of land irrigated is but an estimate owing to the absence of published data and the difficulty of getting at the records kept at the tax offices. King estimated the area of irrigated rice in China at 50,000,000 acres, and more recent estimates (1923) place the area of irrigated rice lands at 43,000,000 acres and the area of gardens and fruits, part of which are irrigated, at 16,000,000 acres. It is probably safe to conclude that over 50,000,000 acres of cropped land is irrigated, and if this be so, it places China in the lead of nations in respect to the extent of its irrigated lands. China also leads the world in the production of rice, tea, silk, soy beans and grain sorghums.

Generally speaking, the climate of China is divided into two distinct seasons; the dry, cool season from November to April during which north winds prevail, and the moist, hot season from May to October when south winds prevail.

King states that in the more densely populated parts of China, the cultivated fields are very nearly level or are made so by grading. The fields upon which rice is grown are surrounded by low dykes and the water is pumped into them by crude pumping devices such as the hand pump, the foot pump, pumps operated by animals and windmills (Fig. 112).

An English writer thus describes the growing of rice in the watershed of the Min river.

> The ground is prepared in spring for the first crop of rice as soon as the winter green crops are removed from the fields. The plow is a crude implement drawn by a buffalo or bullock, and as the land is irrigated before being plowed the plow merely turns up a layer of mud and water 6 inches or more in depth, which lies on a solid floor of hard, stiff clay. After the plow comes the harrow and the transplanted rice. The rice seed is sown thickly in small patches of highly manured ground and when the plants are a few inches high they are dug up, removed to the field and planted in water about 3 inches deep, in rows 10 inches apart, and about the same distance apart in the rows. When water is available the fields are kept covered with water until a short time before harvested.

In the south, the first crop is fit to cut by the end of June or the beginning of July. Before it is quite ripe another crop

of seedlings is started and is ready for transplanting by the time the first crop is off. This second crop is ready for cutting in November.

A consular report states that there appear to be no national or governmental system of water distribution in China. Neither are there any laws governing the use of water. Custom rules in this as in almost all the affairs of life in China. The canals are free and there are no expenses to the user beyond those of drawing the water from the canals. The system of water distribution

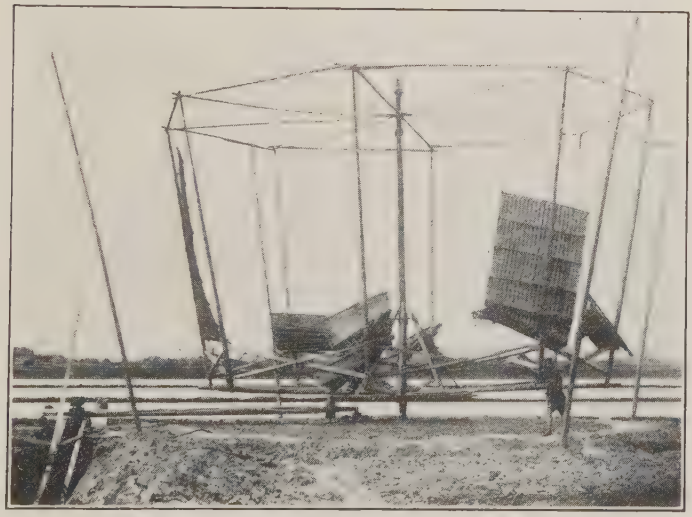


FIG. 112.—A Chinese windmill.

is generally conducted and used on the mutual or cooperative plan. This method prevails in China in so many branches of industry and business as to lead one to believe it is reduced to a perfect system on the basis of equity.

68. Irrigation in Siam.—The kingdom of Siam in southern Asia comprises an area of 242,587 square miles and has a population of 6,230,000. Nearly the entire population outside of Bangkok, the capitol and metropolis, is engaged in the growing of paddy (uncleaned rice). The country exports annually 500,000 long tons of this crop worth about $30,000,000, in addition to

what is consumed as food locally. The Siamese rice is considered to be the best in the world.

Since rice is the main source of revenue, the government is desirous of reclaiming by irrigation and drainage a larger area of land to be planted to rice. Furthermore, five-sixths of the total land tax is from rice lands; hence the internal revenue is largely derived from this crop. The rental of rice land varies from $1 to $10 per acre. The best rice land is worth about $75 per acre.

A fair average yield of paddy is 35 bushels per acre or about 27 bushels of cleaned rice. The common practice is to sow in seed-beds and transplant. The area of the seed-beds is from one-tenth to one-twentieth of that of the fields.

About 4,000,000 acres are under cultivation in Siam nearly all of which lies in the plains of central Siam, and of this area 2,000,000 acres are at present irrigated. Water for irrigation is diverted from the Menam Chao Bhraya, the Prasak, the Nagorn Nayok, the Prachin, the Neklolng and from a few minor streams. Of these by far the most important is the Menam Chao Bhraya, whose source is in the hill region of northern Siam.

The average rainfall in central Siam is about 57 inches per annum. The wettest months of the year are July, August and September, and the driest months are November, December and January, December being practically rainless.

Irrigation has been practised in a crude way since very ancient times but the building of modern irrigation systems was not undertaken until quite recently, dependence being placed on the rainfall in growing rice. As a consequence, famines were of frequent occurrence and about 1902 the government began a study of the irrigation possibilities of the plains of lower Siam. A Royal Irrigation Department was formed and extensive surveys have been made. Several projects have been recommended for immediate construction by T. R. J. Ward, Irrigation Engineer of the Indian Public Works Department, who was invited by the government of Siam in 1913 to come to Siam for the purpose of evolving a scheme of irrigation to embrace as much of the valley of the Menam Chao Bhraya as possible for a capital outlay of about $8,500,000. The Subharn Canal, the Bejaburi East Canal, the Prasak South Canal, the hill irrigation scheme, and navigation and drainage works in the flat plains are

included. Mr. Ward has also recommended that the government construct the minor village works, making a loan to the villages for the purpose and charging a suitable interest.

The various schemes proposed, including those mentioned above, will reclaim and irrigate annually about 1,800,000 acres but will command an area of about 3,200,000 acres. These works when completed are estimated to cost $34,000,000.

The use of water in irrigation in Siam has been the subject of careful investigation on the part of W. B. Freeman, an American irrigation engineer, who was one of Mr. Ward's staff. In designing channels and structures for rice irrigation, Mr. Freeman allowed an average duty of water of 1 second-foot for each 55 acres for an irrigation season of 6 months.

69. Irrigation in the Philippine Islands.—The group of islands making up the greater part of the Philippines has an area of approximately 115,026 square miles or 73,600,000 acres, which is almost equal to the area of the New England states, New York and New Jersey combined. The largest islands, Luzon and Mindanao, have areas of 40,969 and 36,292 square miles, respectively. The next nine in importance range in land area from 5,000 to 1,200 square miles. The islands are traversed by three mountain ridges, mostly of volcanic origin, which contain peaks having an altitude of over 10,000 feet. The plains are fertile alluvial districts, some of considerable extent, which lie along the courses of the rivers and between the sea and mountain ranges.

The Philippines have many rivers, small streams, and lakes. The rivers have their sources in the hills, and traverse fertile valleys to the sea. There are eight rivers of importance, the principal ones being the Rio Grande, Abra, Agno, and Pampangan, on the island of Luzon. Others are the Mindanao, Aguson, Pulangui, the O'Donnell and Pillar rivers. The larger streams have a minimum flow varying from 500 to 3,000 cubic feet per second. Their discharge is subject to great variation, due principally to the tropical storms and the short length of the streams. The Agno, for example, has a flow of 500 cubic feet per second, but during a severe storm the flow was estimated at 280,000 cubic feet per second.

The climate is distinctly tropical, except in altitudes above 5,000 feet, where it is quite temperate. The mean annual tem-

perature at Manila is 80°F. The hottest season is from March to June, when the heat ranges from 80 to 100°F. The coolest weather prevails in December and January, when the maximum temperature is usually slightly above 75°F. There are two distinct seasons, the wet and the dry. From December to May the rainfall is scant, ranging from 10 to 100 millimeters at Manila, while the remainder of the year has an abundance of rainfall, the monthly average varying from 135 to 380 millimeters.

The principal industry of the Philippines is agriculture, and 40 per cent. of the population is engaged in farming. The leading products are rice, hemp, tobacco and sugar cane. In 1903, only 9.5 per cent. of the total area of the islands, or approximately 7,040,000 acres, was included in farm lands, and only about one-half, or 3,520,000 acres, was under cultivation. Of the total area under cultivation but 3.5 per cent., or 125,000 acres of this land, was systematically irrigated at this time. In 1911, 94.5 per cent. of the total area under cultivation, or 2,578,077 acres, was devoted to the culture of rice. The Irrigation Division of the Bureau of Public Works is the authority for the statement that approximately 1,200,420 acres may be brought under modern irrigation. The islands of Luzon and Cebu have by far the greatest percentage of farm lands. The Philippines have a few large farms and many small ones, and the average size of a farm on the islands is but 8.6 acres.

Irrigation is essential during the dry season. One writer says: "The distinct seasons are the prime reason for irrigation," the rice crop requiring a great deal of water. The production of rice in the Philippines is not sufficient for the needs of its own people. This surprising fact necessitates further development of its irrigation possibilities. With the aid of controlled irrigation the Filipino can at least double his rice production, obtaining two crops in a year instead of one.

Irrigation in the Philippines began thousands of years ago with the savage tribes that inhabited the islands, and is practiced by them today. The work accomplished by the Igorrotes, the Ifugaos, and other tribes was to conduct water to the terraced rice paddies on the mountain sides.

The most wonderful rice terraces in existence today are those built by the Ifugaos and located in the heart of Luzon. They

greatly surpass other terraces in the Philippines, Java and the Andes. One author describes them from an "industrial standpoint" as the "most colossal undertaking in the Philippines and the most stupendous task ever undertaken by savages." Viewing them with the eye, he believes them to rival the Pyramids of Egypt and the Great Wall of China and as a great utility and example of engineering skill equal to the Roman aqueducts. These terraces begin at the valley level and extend to the top of the mountain and around its contour. One, in particular, has a vertical extension of 3,000 feet. The terraces range from 8 to 40 feet in width, and from 300 feet to 1/2 mile in length without varying 2 inches in elevation. Each terrace has an outside wall from 6 to 18 feet in height which extends to the terrace below to form its inside wall. In Nueva Vizcaya, 3 miles east of Quiangan is an excellent example of irrigation as practised by the Igorrotes. There is no limit to the extent of these terraces except the size of the mountain on which they are built. In many cases these terraced mountains have the appearance of being sculptured, and not creations of nature.

The savages simplify and facilitate their rice growing by irrigating and fertilizing in a single operation. A writer describes this method in part as follows:

> The water deflected from mountain streams or arising from springs passes through decomposed vegetable matter, ashes, black alluvial soil and other fertilizing material and is carried to the uppermost rice terrace. It carries in suspension this rich fertilizing matter which is distributed on the rice paddies. The water descends from the terrace to the one below, carrying with it much fertilizing material.

The savages do not use animals to till the soil, all the work being done by manual labor. They seem to be ignorant of the use of dams, but the water-tight aqueducts for carrying water to the terraces, made of hollow trees, are many and unique in construction.

The progress of irrigation in the Philippines made under Spanish rule began over 200 years ago, although the Spanish government did not encourage irrigation. The Spanish friars acquired much rice holdings on the islands which necessitated the construction of irrigation works.

From the time the United States acquired the Philippines until 1907, but little attention was devoted by the Insular Government to irrigation. About this time the necessity of government aid for irrigation was realized, probably brought about by the realization of the great importation of rice to the islands, amounting to $5,000,000 in value annually. Previous to 1907, the only work done by the government was limited to repairs in Friar lands systems and limited investigations of irrigation projects. The *Insular Bureau Report* of 1905 calls attention to the great lack of surveys and investigations concerning the topography, hydrography, storage and irrigation possibilities of the islands. In 1907, a small appropriation was made "for the construction and maintenance of irrigation plants and systems in the provinces subject to allotment and regulation as to the use of water and the charge therefor by the Secretary of Commerce and Police." Since that time annual appropriations have been made and are gradually increasing to secure necessary data. A Division of Irrigation was formed in the Bureau of Public Works in 1908.

The first and largest irrigation project in the Philippines undertaken by the government is San Miguel project, begun in 1910, located near San Miguel, Tarlac Province. The water is taken from the O'Donnell River, and is admitted to the canal by nine head gates of modern construction. This river carries in suspension much sand, and it was found necessary to construct a settling basin. The San Miguel dam built for the storage of the flood waters is of steel and concrete, and all necessary precautions were taken in its construction to provide for the large and sudden floods peculiar to the country. The drainage area above the dam is about 300 square kilometers.

In the *Bulletin* of the Bureau of Public Works for January, 1924, is given a list, reproduced in Table No. 50, of the irrigation systems either completed or underway since 1918.

70. Irrigation in Mesopotamia.—The lower portion of the Mesopotamian plain known as Babylonia resembles in many ways the central plain of California. This is true in regard to water supply, climate, extent of arable land and the crops that can be grown. The Tigris River is larger than the Sacramento River during its low-water stages and carries as much water in high floods. As a result of winter rains and the melting of the

TABLE NO. 50

Project	Province	Irrigable area, hectares	Estimated cost, pesos	Allotments authorized, pesos	Total expenditures and liabilities, pesos	Percentage of work completed
Trinidad	Mountain Province	200.0	40,000	40,000	40,000	Completed (1921).
Santa Barbara	Iloilo	4,945.6	692,000	692,000	692,000	Completed (1922).
Dingras	Ilocos Norte	1,009.5	130,000	130,000	130,000	Completed (1922).
Baruyen River	Ilocos Norte	810.7	89,000	89,000	89,000	Completed (1923).
Naic	Cavite	676.0	300,000	292,000	292,000	Completed (1923).
Aganao River	Iloilo	5,500.0	917,000	917,000	908,335	Completed (1923).
Talavera River	Nueva Ecija	8,000.0	1,050,000	1,028,000	1,020,026	90 per cent. completed.
Tagudin River	Ilocos Sur	1,500.0	350,000	325,000	314,869	70 per cent. completed.
Amburayan River	La Union	4,500.0	950,000	844,000	824,566	65 per cent. completed.
Angat River	Bulacan	25,000.0	4,500,000	3,250,000	3,000,830	52 per cent. completed.
Lamao	Bataan	160.0	30,000	5,000	3,424	2 per cent. completed.
Laoag-Vintar	Ilocos Norte	6,000.0	1,000,000	700,000	690,229	20 per cent. completed.
Dipolog	Zamboanga	1,000.0	110,000	97,500	54,076	50 per cent. completed.
Sibalom-San Jose	Antique	4,000.0	500,000	300,000	140,175	2 per cent. completed.
San Miguel Extension	Tarlac	4,500.0	380,000	.....	.....	No funds.
Penaranda River	Nueva Ecija and Bulacan	18,000.0	2,250,000	.....	.....	No funds.
Totals	.....	85,801.8	13,288,000	8,709,500	8,199,530	

snow in spring on the Armenian mountains, high floods are the rule rather than the exception, and these being much too large for the stream-bed to carry, overtop the banks and inundate millions of acres of arable land. The Euphrates River may also be compared in volume with the San Joaquin River but, like it, its flood flow is more easily controlled. The Babylonian delta contains more arable land than is to be found in the central plain of California, the approximate figures being 12,000,000 acres for the former and 10,000,000 acres for the latter. In both there is a long, dry summer followed by a short, rainy winter with maximum temperatures in summer reaching to 120°F. and falling to 20° above zero in winter. While the precipitation on the mountains and high tablelands approaches that on the Sierras, the annual rainfall of the valley is somewhat less than that of the San Joaquin Valley. These striking resemblances in everything essential to irrigation farming tend to produce the same wide diversity in crops which range from the hardy cereals such as wheat and barley through the intermediate crops of beans, corn, alfalfa, cotton and decidious fruits to the semitropical products of oranges and dates.

These two irrigated valleys though alike in physical conditions differ widely in some other respects. In one, irrigation has been practiced for over 6,000 years and the other had its origin within the memory of men still living. California has passed through but two dynasties; the plain of Shinar has been under the sway of a large number of rulers in its time. Persians, Assyrians, Greeks, Romans, Arabians, Turks and the Allies have each played a leading part in the destiny of this country. In the development of the new, is it not possible to be guided somewhat by the experience of the old, gained through centuries of toilsome endeavor? Apart from the destructiveness of wars and the advantages of a stable government, the long record of Babylonian history shows the need of the conservation, control and skilful use of the available water supply. When a part of the surplus waters of the Tigris and Euphrates rivers were stored in reservoirs, when the irrigated lands were protected by heavy levees and when the entire plain was a network of canals and drains, as was the case in the days of Nebuchadnezzar, and later under the rule of Alexander the Great, the country prospered; but

whenever the power emanating from a central government relaxed or became impotent, the irrigation works so vital to the welfare of the inhabitants could not be maintained and once fertile lands reverted to barren deserts or unhealthy marshes.

Under the protective control of the British Empire this ancient land is being gradually restored to order and prosperity. The newest airplanes of the British Air Force patrol Babylonia and Assyria with headquarters near Bagdad on the Tigris. American motor cars are taking the place of the camel and the caravan and plentiful supplies of petroleum are found at Mosul. Mountain streams are being utilized for the creation of light and power and the valley of the Jordan in Palestine and other fertile plains are being irrigated. The dawn of a new era is in sight for Mesopotamia.

71. Irrigation in Australia.—Irrigation in Australia is in its infancy. At present (1924) large areas of irrigable lands are undeveloped and but slightly utilized by a relatively small number of stockmen. As time goes on, however, people in less-favored climates will take advantage of the mild winters and temperate summers of this island continent and immigrate to its shores in quest of farms and homes. Since fully three-fourths of the country is either arid or semiarid, there can be little development in agriculture beyond that which has already taken place without the aid of irrigation. This doubtless accounts for the fact that the Commonwealth is cooperating with several of the states in the building of large irrigation works and the colonizing of irrigable lands. Furthermore, the governments of the majority of the states are enacting legislation and providing administrative machinery with a view to establishing this basic industry on a broad and safe foundation.

In 1915, an agreement was entered into by the states of New South Wales, Victoria, South Australia and the Government of the Commonwealth of Australia, for the development, at a cost of about $45,000,000, of irrigation schemes in the three states mentioned, supplies for which will be drawn from the Murray River.

Thus far, comparatively little land in Australia has been actually irrigated, but works have either been built or are under construction to provide a water supply for large areas of land. In Victoria, the area actually irrigated at the present time is

less than 500,000 acres but the area supplied with water for domestic and ordinary use and for watering stock is approximately 10,880,000 acres. Under the direction of Dr. Elwood Mead, effective methods of colonizing the irrigable holdings have been devised and put into successful operation. Briefly stated, these consist of: (1) long time and low interest in paying for land; (2) no charges for water rights and only an annual charge to meet interest and operating expenses, the average price of water being $1.25 per acre-foot measured at the place of use; (3) small advances to settlers to aid in contructing needed buildings and in preparing a part of their holdings for successful irrigation and profitable crops; (4) the establishment by the state of cold-storage plants, cooperative dairies, canning factories and the like.

Little progress was made in irrigation in South Australia until 1910, when an irrigation and reclamation works department was created. At present the government is proceeding with the preliminary surveys and construction of a number of irrigation enterprises along the Murray River. The Cobdagla estate, formerly held under grazing permits, has been resumed by the crown and as the result of the surveys to June 30, 1913, 11,400 acres have been found available for irrigation. Additional irrigable areas are being developed at Berri. A large central pumping station has also been erected at the south end of Lake Bonney to command adjacent irrigable lands. The maximum lift is about 90 feet.

Tasmania, one of the six states which form the Commonwealth of Australia, has an area of nearly 17,000,000 acres, but its population in 1914 was only 200,000. At present about 10,000 acres are under irrigation and plans are being matured for enterprises which will include much larger areas.

The state of Western Australia is likewise making preliminary surveys for irrigation enterprises, one of which includes a scheme to irrigate 100,000 acres.

An idea of the present status of irrigation in the various states of Australia can probably best be conveyed by a description of one, namely, New South Wales.[1] In this state thus far only one large national scheme has been developed, that of the Murrumbidgee irrigation enterprise. This is intended to provide for

[1] Extracted from report prepared by G. J. Evatt.

about 6,000 farms or 200,000 acres of irrigable land to which is attached about 1,000,000 acres of non-irrigable holdings. Before the European War put a stop to immigration, this large tract was being rapidly settled. At the close of 1921, 1,781 farms were settled representing an acreage of 108,241 acres.

The cost of a water right under the Murrumbidgee project averages about $22.50 per acre. The government does not aim at making any profit out of the enterprise. The irrigable lands under the project were purchased by the government from private holders at an average cost of between $12.50 and $15 per acre. The title to the farms is leasehold in perpetuity and it has been calculated that a rental of 2 1/2 per cent. based on a capital value of from $15 to $40 per acre, according to the quality of the land irrigated, will enable the state to meet the obligations already mentioned. The annual rental paid by the water users is $1.25 per acre-foot. The water is delivered to the farmers by rotation. The period was originally a three-weekly one but during the last two seasons it has been reduced to 15 days. Farmers notify the superintendent of water distribution 5 days beforehand as to their requirements and a supply is given. Special waterings can also be arranged. The matter is left entirely to the judgment of the superintendent of water distribution. When it is granted a nominal charge is made for such a special watering.

In the methods of preparing land and applying water there has been no important departure from American practice. The implements used are in most cases identical with those in common use in the United States. Flooding between check banks is a method commonly adopted for irrigating alfalfa. The land is made level transversely and a continuous fall is provided for to insure the excess of water being readily drawn off. The chief difference between Australian practice and the so-called border method of the United States consists in the shorter length of the borders, which varies from 200 to 400 feet.

Flooding in paddocks or sections is also practiced in irrigating alfalfa and cereals. This corresponds closely to the check irrigation methods of California.

Southeastern Australia possesses one of the largest artesian basins in the world. The southern half of this great natural underground reservoir lies in the northeastern portion of the

state of New South Wales, and it would be hard to estimate the benefits both pastoral and agricultural that have been derived from the tapping of this subterranean supply. Within this district no less than 531 wells have been put down to depths varying from 100 to 338 feet. The rate of flow from these varies from a pumping supply to a natural flow of 1,250,000 gallons (Imperial) per day and the total flow per day from all the wells in the artesian basin is upward of 100,000,000 gallons. The artesian wells are utilized largely for stock-supply purposes but the water is also used for irrigation, although the presence of mineral salts in some of the well waters militates greatly against their value for irrigation.

72. Irrigation in Western Canada.—So far, irrigation in the Dominion of Canada has been confined to the provinces of British Columbia and Alberta, together with a small area (10,000 acres) in southwestern Saskatchewan. Compared with the country to the south, the need for irrigation is less in that broad expanse of territory which stretches from Halifax on the east to Vancouver on the west. This is not so much due to a larger annual precipitation as it is to a smaller loss of water by evaporation. A rainfall which will barely support desert plants in Colorado and New Mexico suffices for a fairly dense forest growth in parts of British Columbia; yet notwithstanding the fact that a large percentage of the moisture which falls from the clouds is available for plant growth, the necessity for irrigation has long been felt in both British Columbia and Alberta and large amounts of capital have been invested in irrigation works in both provinces. In recent years the cost of the works built by the Canadian Pacific Railroad in the province of Alberta reaches the large aggregate of $20,000,000 and individuals and private irrigation companies have expended nearly as much more in British Columbia. A brief outline of what has been accomplished in irrigation up to the close of 1922 in the two western provinces is here given.

Alberta.—The arid portion of this prairie province occupies a belt approximately 160 miles in width north of the state of Montana and extends from the Rockies on the west across the entire southern base of the province and merges into the more humid climate of Saskatchewan in the eastern limits of Cyprus hills district of southwestern Saskatchewan.

The climate conditions of Calgary are representative of the western portion of Alberta and in that city for the 5 months of May to September, there is an average precipitation of about 10 inches which is increased to 15 inches for the entire year. In the vicinity of Medicine Hat, in the eastern part of the province, the summer and annual precipitations are about 20 per cent. less. Although the precipitation is less than it is at Greeley, Colo., good cereal crops can be grown without the aid of irrigation in seasons of more than normal rainfall. It is to insure against crop failures in dry seasons that irrigation has been provided for.

One of the oldest irrigation projects in Alberta provides water for lands in the neighborhood of Lethbridge. This enterprise was first known as the Alberta Irrigation Company, but after reorganization it became the Canadian Northwest Irrigation Company and still later the Alberta Railroad and Irrigation Company. In 1912, it was taken over by the Canadian Pacific Railroad Company and has since been operated with other similar enterprises by the Department of Natural Resources of the company. This system diverts water from the St. Mary's River through a canal of 1,000-second-feet capacity for the irrigation of 100,000 acres, of which more than one-half were irrigated in 1915. The capital cost has been $1,326,000. The annual rental paid by the water users is $1 per acre. The bulk of the land around Lethbridge is naturally smooth and possesses an ideal slope for distributing water. In consequence the preparation of land costs on an average less than $5 per acre. The success of this project has been largely due to the growing of alfalfa, which forms a large percentage of the total cropped area under the canal. Alfalfa has not only proved profitable as a fodder, selling for $10 to $15 per ton, but also as a renovator of soils and as a basis for crop rotation.

By far the largest irrigation project owned and operated by the Canadian Pacific Railroad Company lies immediately east of Calgary and embraces a block of 3,000,000 acres located between the Bow and Red Deer rivers. This block is divided into the central, western, and eastern sections. About 21 years ago, the construction of a system for the irrigable lands of the western section was begun and water was first used in irrigating land in 1909. This system (Plate VI) diverts water from Bow River

through a costly intake structure at Calgary and consists of 17 miles of main canal, having a capacity of 2,300 second-feet, 254 miles of secondary canals and 1,300 miles of distributaries with their accompanying structures. These channels command an areas of over 1,000,000 acres, of which by the first estimate 350,000 acres were said to be irrigable; but as a result of more accurate surveys this estimate has recently been reduced to about 250,000 acres. The cost of the western section to date is approximately $4,325,000 or $17.30 per acre.

The works for the eastern section have been completed at a cost of about $10,000,000. These comprise a diversion dam and intake on Bow River near Bassano, costing $1,500,000, 5 miles of main canal, 475 miles of secondary canals and 2,020 miles of distributaries. The channels command an area of about 1,250,000 acres, of which 425,000 acres are classed as being readily susceptible of irrigation.

The central section comprises an area of 830,000 acres but no efforts have as yet been made to construct the necessary works.

Irrigable land sells for $35 to $60 per acre, the higher prices being asked for lands near towns and railway stations. Water users pay yearly only 50 cents per acre on the western project but this price having been found too low, a rate of $1.25 per acre is charged on the eastern section.

The status of irrigation development in southern Alberta and southwestern Saskatchewan at the close of 1922 is outlined in Table No. 51. extracted from the *Annual Report* of the Reclamation Service of Canada for 1922–1923.

As regards duty of water in the province of Alberta, this is fixed arbitrarily by the terms of the Dominion irrigation act at 2 acre-feet per irrigable acre for the season. The actual amount of water required for maximum plant growth varies considerably with the kind of crop and other conditions but experience has indicated that an average net duty of from 15 to 18 inches is all that is required for average crops.

The methods followed in preparing land and applying water do not differ in any essential part from those practiced in the United States to the south.

British Columbia.—This province is wonderfully rich in natural resources. For more than half a century the mines have

FIG. A.—Secondary canal of Western Section Canadian Pacific project, Alberta.

FIG. B.—Concrete drop in secondary canal of same project.

(*Facing page 402.*)

TABLE NO. 51.—IRRIGATION DEVELOPMENT IN WESTERN CANADA

Project	Source of supply	Area of tract, acres	Irrigable area, acres	1922 operations		Capital cost	Mileage of canal
				Number of water-users	Area irrigated, acres		
Constructed and in operation:							
C. P. R. Western Section	Bow River	1,145,336	218,980	967	49,752	$5,353,440	1,469
C. P. R. Eastern Section	Bow River	1,212,074	400,000	893	93,375	11,132,169	2,500
Alberta Railway and Irrigation Company	St. Mary River	434,509	130,000	865	75,558	1,900,000	225
Taber Irrigation District	St. Mary River	30,365	17,244	128	13,122	272,330	73
Under construction, partly in operation:							
Canada Land and Irrigation Company	Bow River	452,482	202,640	64	9,809	6,541,207	377
Constructed, operation to commence 1923:							
Lethbridge Northern District	Oldman River	231,220	105,000	...	.....	5,400,000	
United Irrigation District	Belly River	64,600	26,000	...	.....	524,000	
Little Bow District	Highwood River	11,490	3,278	...	.....	36,000	
Found by surveys to be feasible (district) organized):						Estimated cost	
New West District	Bow River	13,015	4,501	...	.....	160,000	
Medicine Hat East Irrigation District	Ross Creek	4,800	2,900	...	.....	36,000	
Macleod Irrigation District	Waterton River	108,603	49,649	...	.....	2,060,000	
Found by surveys to be feasible (not organized):							
Eyremore District	Bow River	18,776	4,100	...	.....	250,000	
Bow River Irrigation District	Bow River	16,688	5,792	...	.....	314,357	
Lethbridge Southeastern District	Watertown, Belly, St. Mary, and Milk Rivers	1,182,781	414,400	...	.....	16,622,000	
Robsart-Vidora project	Frenchman River	14,000	10,000	...	.....	343,841	
Retlaw-Lomond Irrigation District	Bow and Oldman Rivers	418,630	115,000	...	.....	2,500,000	
Champion Irrigation District	Highwood River	184,860	50,000	...	.....	2,071,000	
Granum Irrigation District	Willow Creek	.....	4,500	...	.....	260,000	
Beaver Creek project	Beaver Creek	.....	9,000	...	.....	450,000	
Preliminary surveys:							
North Saskatchewan Irrigation project	North Sask., Clearwater, Raven and Red Deer Rivers	3,538,760	1,400,000				
493 small private schemes	.....	.....	114,089				

been producing gold and silver, lead and copper, coal and coke, in steadily increasing quantities. The total revenues derived from the sale of timber exceeds those from all other soil products combined. In short, the output from the mines and forests, the yearly catch of salmon, the extension of grain raising on dry farms, the large expenditures in civic improvements and the building of highways and railways have tended to draw the attention of the people away from irrigation and to subordinate this basic industry to none the less important but less permanent development.

Southern British Columbia, containing an area equal to the entire state of Colorado, is divided into a succession of long narrow valleys by five or six mountain ranges which run north and south. A typical feature of most of these valleys is a long narrow lake which also has a general north and south direction and thus parallels the range and valley on each side. The low elevation of these mountain valleys, the mildness of the winter climate and the fertility of the soil render them well adapted to the production of a fine quality of deciduous fruits and berries when the natural aridity is overcome by artificial waterings.

E. Davis, Chief Engineer[1] of the Department, states that owing to the wide range in climatic conditions in the province, three methods of irrigation are practiced. On the coast, and in parts of the West Kootenay District where the climate is fairly humid, irrigation by spraying is common. In the Dry Belt of the interior at the lower elevations water is used in much the same way that it is in the western states, whereas at the higher elevations of the interior, native meadows are irrigated by wild flooding similar to those of Oregon or Nevada. The duty of water as fixed by the board varies from 1 to 3 acre-feet per acre.

Exclusive of individual effort, about 60 irrigation companies have been organized to build works and sell land and water rights to settlers. So rapid a development in diverting and using water soon led to controversies which in turn induced the government of the province to engage experts for the purpose of making a thorough study of irrigation conditions and of framing the necessary legislation. As a result of such investigations, the province can now boast of an irrigation code inferior to none on the North American continent.

[1] *The Irrigation Review*, July, 1924.

In 1909, there were 8,000 unsettled claims to the use of water. At that time the water-rights branch of the Department of Lands consisted of a chief water commissioner, two board members who gave only a small part of their time to official duties, and three surveying parties engaged for the summer season. Four years later there was a staff of over 50 members, consisting of the Commissioner of Water Rights, 3 members of the Board of Investigation, 8 district engineers, and over 20 surveying parties. With such a staff, the old records can be surveyed, platted, investigated, determined and licenses either granted or denied at the rate of about 100 per month. Of the first 2,000 claims that were determined, only two were appealed to a higher court. At the close of 1923, 7,000 water-right records have been investigated and licenses granted to all that were bona fide. There have been few appeals from the decisions of the board and of these only three have been adverse. In this way the administration of the province hopes to free the water users from litigation, the curse of irrigated countries.

73. Irrigation in Argentine.—Dr. Bailey Willis in his work on Northern Patagonia, states that three-fifths of the area of Argentina has less than 20 inches of rainfall. From the Chubut River north for a distance of 1,500 miles, there is an immense area located on the eastern slope of the continental range which has less than 10 inches of rainfall. East of this long belt is another which has an annual precipitation of less than 16 inches, and still east of this lies a larger belt in which the precipitation ranges from 15 to 30 inches per annum. In view of such arid conditions Willis may well state that "the conservation of the waters and their utilization to the greatest possible extent of economical service is the most important factor among the natural resources of this republic."

The valley which presents the best prospects for irrigation and intensive agriculture is that of the Rio Negro. This stream, which has a mean annual discharge of 17,000 second-feet, is dependent for its supply on two main tributaries, the Limay and the Neuquen, both of which rise in the Andes but nearly 300 miles apart. The drainage basin of the Rio Negro and its tributaries contains about 9,000,000 acres and at present supports on an average a sheep to each acre.

The condition of Argentina today does not differ from that which prevailed in the states of the Rocky Mountain region 45 years ago. Stock-raising is the main industry. There are said to be 20,000,000 head of cattle and 80,000,000 sheep. In course of time these conditions will change. The large ranches will be subdivided; irrigated farms will be formed out of arid pasture lands and a larger and more stable population will depend on the irrigated farms for sustenance.

In recent years the national government has taken an active part in the development of irrigation. In most cases it provides the funds for construction in the form of loans to the provinces, which repay them on easy terms. Projects approved are to cost a little less than $2,000,000. The railway corporations have likewise cooperated with the government and the more arid provinces in furthering the interest of irrigation farming.

According to a list of irrigation projects prepared by special agent, J. A. Massel, the total area under completed projects aggregates 1,116,200 acres and the area under proposed and partially completed projects amounts to about 3,221,000 acres.

74. Irrigation in Colombia.—Little progress has been made in irrigation development in Colombia, but the need for better protection against prolonged droughts is keenly felt. The stock and farming interests of the country are urging the national govern-

	1909, inches	1910, inches	1911, inches	1912. inches	1913, inches	1914, inches
January	0.54					
February	0.05					
March						
April	1.93	1.05	1.78	.....	0.69	0.20
May	9.02	4.44	1.27	0.13	1.35	0.94
June	2.02	5.67	0.80	1.47	2.14	1.11
July	7.89	6.85	0.80	0.88	0.11	
August	14.71	8.05	0.64	0.54	3.40	1.12
September	5.11	6.78	1.36	7.56	5.00	0.49
October	8.56	9.51	5.29	10.78	2.07	7.26
November	18.00	6.32	2.12	2.56	10.90	3.22
December	0.55	1.42	.....	0.05	0.60	1.57
Total (in inches)	68.38	50.09	14.06	23.87	26.26	15.91

ment to take steps to protect these industries. The uneven distribution of the rainfall and its wide variations from year to year are shown in the foregoing table from Consul Ross Hazeltine's report of the rainfall of Cartagena.

75. Irrigation in Northern Brazil.—The states of Piauhy, Ceara, Rio Grande de Norte, Parahyba, Pernambuco, Alagoas, Sergipe, and Bahia, in northeastern Brazil, embracing an area of nearly 300,000,000 acres, consist of a coastal belt of limited area, an interior undulating plain and extensive tablelands that rise above the plains to elevations of from 1,500 to 2,800 feet. This region is arid rather than tropical, being covered with cactus, brush and dwarf trees, although the equator is only 8 degrees north of its center. Over the greatest part the annual rainfall is less than 20 inches and the entire region is subject to prolonged droughts. It was to relieve the famines which such droughts produced that the Government of Brazil organized in 1904 three Federal bureaus known as the Reservoir Commission, the Drought Commission and the Commission for Sinking Wells. In 1909 these commissions were consolidated into the *Inspectoria de Obras Contral as Seccas*, or Drought Service, and placed in charge of M. A. R. Lisboa as chief. So far the Service has devoted its energies mainly to surveys, studies of the water resources, and to the building of reservoirs.

76. Irrigation in Peru.—The republic of Peru occupies a portion of the west coast of South America from a point near the equator to latitude 19 degrees south. It is traversed from north to south by the Andes Mountains which contain a number of lofty volcanic peaks. The Amazon River has its source in these mountains and the greater part of Peru lies in the watershed of this river and its tributaries. The only arid portion of Peru is the narrow strip of coastal plain having an average width of 30 to 40 miles, and consequently all the irrigation is found in this strip. This plain is watered by about 65 rivers of perennial and intermittent type having their sources in the Andes and crossing the plain to the ocean, in many cases forming alluvial fans at their mouths.

The land already under irrigation embraces a total area of approximately 640,000 acres and the additional area which may ultimately be irrigated at a reasonable cost is estimated to be 640,000 acres, also. The area possible to irrigate is limited in

part by the coarse quality of the soils in some sections and by the scarcity of suitable storage sites for conserving the flood waters. Much land that is well situated topographically for irrigation is found to consist of shallow, highly alkaline soil lying directly on the rock, and, again, good land is found along streams where all available water supplies are already fully utilized.

The mean annual temperature varies from 50°F. in June and July, to 90° in February and March. It is, therefore, possible to grow crops at any time of the year, but the most favorable time for planting cotton and other staple crops is in the spring from August to November. The climate is remarkably uniform throughout the coast country due to the Humboldt current which passes along it.

The rainfall of the coastal plains of Peru, with the exception of the extreme northern part, is very light, not exceeding 2 or 3 inches per year. During the cooler winter months heavy fogs occur in the evenings, sometimes lasting into the late morning hours. Throughout the summer and fall from November to April, there is constant dryness with bright sunshine, considerable midday heat but cool nights.

William White Handley, Consul-General of Peru, states:

> There was practically no development of irrigation in Peru from the time of the Spanish Conquest down to the beginning of the present century. The Spaniards found irrigation works serving about the same area of land as is irrigated today, perhaps a somewhat greater area. Old canals are traceable covering areas now abandoned, sometimes because of lack of water in proper season for export crops such as sugar and cotton. They did nothing to extend or improve the works. It is estimated that over half the lands irrigated at the time of the conquest were granted to various persons enjoying the patronage of the crown, and the lands constituting such grants exist today in large part, in the form of large sugar estates. The irrigation works upon these estates are in the condition in which they were found by the Spaniards. In several valleys, however, the Indian communities were secured in the ownership of their lands. In some cases the lands have descended to the present time in small lots each with a separate proprietor.

The existing works are but the remnants of perhaps the most elaborate and complete system of irrigation ever perfected by man, which covered not only the best parts of the valleys but terraced declivities of the mountains.

The amount of water used in irrigation is subject to seasonal supply. In the spring, September to November, as low as 1 second-foot per 560 acres is used for the production of an average crop of cotton. When water is abundant the duty for an average crop of cotton is 1 cubic foot per second for 200 acres. As the summer advances, floods arrive and there is an abrupt change from scarcity to superabundance of water. Then the duty falls in all cases to 1 second-foot for 70 acres or less. On the sugar-cane fields a high duty may be attained from April to December owing to the frequency of dense fogs at night, so that even when there is an abundance of water the average use on sugar cane during these months is a second-foot for 200 acres.

The principal crops grown in Peru are cotton, sugar cane, grapes and rice. Forage crops are little grown except for pasturing stock, although some alfalfa is raised for sale to the army. Seven crops of alfalfa per acre are cut, the yield varying from 10 to 17 tons. Corn yields an average of 50 bushels per acre, lima beans 40 to 50 bushels per acre. The average yield of cotton is 470 pounds per acre and of sugar cane 4 1/2 tons. No fruit is grown commercially, although all subtropical fruits make good yields when properly taken care of.

A law was passed by the Peruvian government in 1913 providing for the raising of $9,750,000 by the issue of 30-year bonds bearing 5 1/2 per cent. interest at a price not below 87 1/2 per cent., to be devoted to irrigation and colonization, the bonds to be secured on the irrigation works and to be repaid from sales of public lands covered by these bonds.

A number of irrigation projects have been investigated and designed for the Government by G. W. Sutton, Chief of the Irrigation Service. Lands have been expropriated, subdivided, irrigated and settled by natives and, on the whole, considerable progress has been made in irrigation construction and settlement in recent years.

77. Irrigation in Chili.—The republic of Chili is like a ribbon stretched over a distance of nearly 2,800 miles having the high Andean range on the east and the Pacific ocean on the west. This long narrow country is at no place more than 250 miles wide, and is narrowed down in places to a little more than 100 miles. In area it is nearly as large as the combined area of California,

Oregon and Washington, but in population it is not quite equal to California alone having approximately 3,750,000 people. About one-third of the population live in the larger cities and the bulk of the remainder are to be found in the agricultural parts of the country located in the central provinces. Here the climate is temperate, the thermometer rarely descending below freezing or rising above 86°F. and thus permitting the growth under irrigation of most of the cultivated plants grown in the United States.

The climate of Chili varies with altitude and latitude. The influence of the ocean gives to the long coast line a fairly equable temperature but rain seldom falls north of Valparaiso.

The author is indebted to Don Domingo Matte, a Chilian engineer for the data contained in the following table:

TABLE No. 52

Province	Area	
	Irrigated, acres	Capable of irrigation, acres
Tacna	15,263	4,289
Tarapacá	4,372	10,494
Antofagasta		
Atacama	43,800	90,312
Coquimbo	138,734	187,163
Aconcagua	90,747	99,589
Valparaiso	77,490	91,565
Santiago	293,200	205,839
O Higgins	312,343	50,140
Colchagua	343,412	175,876
Curicó	166,778	164,128
Talco	196,793	217,739
Linares	227,611	298,252
Marile	48,558	81,512
Nreble	232,158	498,600
Concepcion	45,820	303,263
Ararico	17,268	176,133
Bio Bio	61,542	263,087
Malleco	52,768	185,083
Caritin	22,746	179,854
Valdivia	36,484	585,056
Llanquihue	14,492	171,720
Chiloe	2,669	50,737
Territory of Magellanes	34	

78. Irrigation in the Territory of Hawaii.—There are eight inhabited and a few uninhabited islands in this territory which extends in a southeasterly direction a distance of 380 miles. The inhabited islands in the order of their area are Hawaii, Maui, Oahu, Kauai, Molokai, Lanai, Niihau and Kahoolawe, the last two containing 106,000 acres. The total area of this group of islands is 4,250,000 acres by far the largest being Hawaii which contains nearly 2,700,000 acres. The greater part of the surface being rocky and mountainous, the improved agricultural land is confined to 300,000 acres, of which about 225,000 acres are devoted to the growing of sugar cane. The crop which ranks second in area is pineapples which are not irrigated, as a rule. Other crops are rice, taro, truck, fruit and coffee. Rice and taro are grown on the low wetlands near tide level and are irrigated. Pineapples, on the other hand, require little moisture and are grown on higher land having fairly steep slopes, good natural drainage and a somewhat limited rainfall. Sugar cane is grown chiefly on the intermediate belt between the rice and pineapple lands.

Much of the land used for growing cane is held in large holdings, chiefly estates, and is leased for long periods of time to plantation companies. Since most of the companies have their own sugar mills there is seldom any conflict of interest between grower and manufacturer.

The first large irrigation project in the territory of Hawaii was completed in 1878. This conveyed water from the forest covered windward slope of East Maui a distance of 17 miles to the dry leeward slope at a cost of $80,000. Since that time more than $20,000,000 have been expended in obtaining water supplies by means of tunnels, canals, pipes, flumes, pumping plants and reservoirs. Many of the companies supplement their gravity supplies by pumped artesian water. Sugar cane is the principal irrigated crop. On account of the large quantity of water used, the long irrigation period, the large percentage of pumped water and the large amount of labor involved in applying water, the cost of irrigating cane is high. This cost on 24 plantations, exclusive of the interest on construction charges for water supplies, averaged, in 1922, $90 per acre.

As regards duty of water for sugar cane, it requires on an average about 19 acre-feet of water per acre to bring the crop to

maturity and the ratio of water requirement is about 3,900 pounds of water to each pound of sugar produced.

Sugar cane is shallow rooted, the deepest roots seldom penetrating more than 4 feet from the surface. The effective water-holding capacity of the lava soil seldom exceeds 4 inches in four feet of soil. The common practice is to apply much more water than the soil can hold, thus causing waste of water by deep percolation and in many cases creating drainage troubles. The management of Hawaiian plantations deserve much credit for what they have accomplished along irrigation lines, but more requires to be done in regard to the time of irrigation and the proper quantity to apply at each watering.[1]

[1] The information contained in this article is derived mainly from "Irrigation of Sugar Cane in Hawaii," by W. P. Alexander, 1923, and "Some Aspects of Drainage in the Territory of Hawaii," by R. A. Hart, Senior Drainage Engineer, U. S. Dept. of Agr., 1923.

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